② LEVEL II

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FINAL REPORT

LARGE-SCALE OUTDOOR FIRE-RELEASED CARBON FIBER TESTS

BY

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JULY 1980

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Source release	Balloon-supported net system	Pool fire burn tests
Source trials	Stainless steel mesh sampler	Vertical sampling array
"Peterson" sampler	Cardboard nylon mesh sampler	Overhead canopy array
Jacob's Ladder	Tower supported canopy array	(over)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Five large-scale outdoor pool fire tests (three source/dissemination and two source) resulted in obtaining characteristic data of carbon fibers released into the atmosphere when carbon fiber/epoxy matrix composite structural components were exposed to large-scale outdoor jet-fuel fires representative of fires expected to be experienced in civil aircraft accidents. Estimated source strength release of carbon fibers varied from 1.1 x 10^8 to 2.9 x 10^8 single fibers released under burn conditions of moderate to high wind speeds (required) in the source/dissemination tests. Estimated source strength data for these trials

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19- Large-scale outdoor fire-released carbon fiber tests
Carbon (graphite)/epoxy composite material
Source strength of single carbon fibers
T300 carbon fiber/5208 epoxy matrix
Carbon fiber recovery "air wash"

20- was derived from fibers captured on a vertical mesh sampler array designed to intercept the fire plume downwind of the source. Estimated single fiber source strengths, derived from the two source burn tests which required wind speeds to be near zero, varied from 2.2×10^8 to 2.9×10^8. The fiber data for these tests was obtained by a passive sampler designed to capture fibers contained in the fire plume and rising from the fire. Good correlation of source strength estimates was obtained by the two fiber sampling methods. The fibers were released during approximately 20 minutes of burning 11356 ℓ (3000 gal) of JP-4 jet aircraft fuel in 10.7-m diameter pool fires. The initial mass of carbon fibers burned ranged from 30 to 50 kg with the mass fraction release of single fibers of approximately 0.1 to 0.2 percent of the initial mass burned.

The mean length of fibers collected on the stainless steel mesh samplers on the vertical array was 4.8 mm while the mean length of fibers collected on the overhead "Peterson" and DPG stainless steel mesh samplers attached to the overhead canopy array was 3.0 mm.

SUMMARY OF RESULTS

The five burn tests resulted in characteristic data on the source of carbon fibers released into the atmosphere when carbon fiber/epoxy matrix composite structural components were exposed to large-scale outdoor jet-fuel fires representative of fires expected to be experienced in civil aircraft accidents. The estimated source strength release of carbon fibers varied from 1.1×10^8 to 2.9×10^8 single fibers released under burn conditions of moderate to high wind speeds. Estimated source strength data for these trials were derived from fibers captured on a vertical mesh sampler array designed to intercept the fire plume downwind of the source. On the two burn trials which required wind speeds to be near zero, estimated single fiber source strength varied from 2.2×10^8 to 2.9×10^8. The fiber data used to derive source strength for these tests were obtained by passive samplers designed to capture fibers contained in the fire plume and rising from the fire. Good correlation of source strength estimates was obtained with the two fiber sampling methods. The fibers were released during approximately 20 minutes of burn. The initial mass of carbon fibers burned ranged from 30 to 50 kg. The mass fraction released as single fibers was approximately 0.1 to 0.2 percent of the initial mass burned.

Fibers collected on the vertical array had a mean length of 4.8 mm. Fibers collected by the "Peterson" and DPG stainless steel mesh samplers attached to the overhead array had a mean length of 3.0 mm. This length difference could be attributed to wind transport of longer fibers passing through the vertical array during the burnout cycle of the fire, or to wind blowing fibers from burned composite after the fire was extinguished.

Visual observations of the plumes and measurements of fiber flux downwind indicated that model calculations of deposition or exposure levels should consider the effluent from the the fires as being emitted from at least two major sources (warm and hot plume). The modeling effort considered a hot plume which is dominant during the fully-developed fire and a warm plume occuring during the fire burnout cycle. Comparison of model predictions and measured values downwind is best described using this technique. The maximum downwind exposure levels were $<10^5$ fiber-sec/m^3 at the first sampling line 60 m downwind, and $<10^4$ fiber-sec/m^3 at distances from 60 m downwind to 19,109 m, the extent of the sampling range.

CONCLUSIONS

1. Single Fibers

a. Estimated source strength varied from 1.1×10^8 to 2.9×10^8 carbon fibers per trial.

b. Length distribution of carbon fibers >1 mm long (sampled on vertical array) varied from trial to trial. However, all distributions were skewed heavily toward the shorter lengths with >14.2 percent <2 mm long, >32.3 percent <3 mm long, and >44.3 percent <4 mm long.

c. Average length varied from trial to trial, probably dependent on:

(1) type of composite material burned

(2) time of fiber release (during or after burn)

Single fiber average length measured in the plume (3.2 mm) was shorter than that outside the plume (4.2 mm).

d. Diameters of released single fibers (average 4.4 μm) were smaller than they were before (average ∿8 μm) being subjected to the pool fire.

2. Clumps of Fibers

a. Estimated source strength varied from 1.6×10^7 to 8.8×10^7 airborne clumps per trial.

b. Size distribution of clumps (measured by the number of fibers per clump) was skewed heavily toward the smaller number of fibers per clump. The clump data from the vertical array shows an average distribution of 30 percent with <5 fibers/clump; 66 percent with <10 fibers/clump; 74 percent with <20 fibers/clump; and 90 percent with <50 fibers/clump.

3. Transport Modeling

The model which best describes downwind transport of single carbon fibers is a combination of hot and warm plume-rise model used in conjunction with a volume-source dispersion model for subsequent downwind dispersion. This combination best describes the transport of single carbon fibers released during a pool fire, while the fire is dying down, and even after the fire is out.

4. Downwind Carbon Fiber Exposure Levels

Maximum downwind carbon fiber exposure levels measured 1.5 m above ground level 60 m downwind of the pool fire were 5.1×10^4, 8.6×10^4, and 1.5×10^4 fiber-sec/m^3 for Trials D-1, D-2, and D-3, respectively. Maximum exposure levels measured at 0.5 meters above ground level at other downwind distances are given in the following table.

Maximum Carbon Fiber Exposure Levels Measured 0.5 M Above Ground, Downwind of the Pool Fire.

Downwind Distance (m)	Maximum CF Exposure Levels (fiber-sec/m^3) Trial D-1	Trial D-2	Trial D-3
207	6.2×10^3	2.1×10^3	2.7×10^3
298	1.3×10^3	0.6×10^3	7.7×10^3
482	0.9×10^3	3.4×10^2	1.1×10^3
665	---[a]	1.3×10^2	5.7×10^2
1030	0.9×10^3	1.3×10^3	5.3×10^2
1398	1.3×10^3	1.3×10^2	2.9×10^2
2206	1.8×10^2	2.1×10^2	5.7×10^2
3824	0.7×10^2	4.3×10^2	2.0×10^2
5421	2.8×10^2	4.7×10^2	2.0×10^2
10261	2.5×10^2	5.6×10^2	0.8×10^2
19109	2.8×10^2	0.9×10^1	1.2×10^2

[a]No data

FOREWORD

The National Aeronautics and Space Administration (NASA), NASA Langley Research Center, Hampton, VA, initiated, sponsored, and funded this test. Mr. Richard A. Pride of NASA-Langley Research Center was the NASA Test Manager. He was assisted by Messrs Thomas N. Bartron, Austin A. McHatton, and John R. Gleason. NASA contracted test assistance with TRW Defense Systems Group, Redondo Beach, CA, for design and fielding the Jacob's Ladder sampling array. The US Air Force Geophysics Laboratory, Hanscom, Air Force Base, MA, was contracted by NASA to provide operational balloon support for deployment of the Jacob's Ladder. The Bionetics Corporation, Hampton, VA provided electonic real-time fiber measurement support, under contract to NASA. Other government agencies with an involvement in evaluating the carbon fiber problem had personnel participating at various times in test preparation and data recovery. These included Air Force Rome Air Development Center, Rome, NY; Army Ballistics Research Laboratory, Aberdeen, MD; National Institute for Occupational Safety and Health, Cincinnati, OH; and Naval Surface Weapons Center, Dahlgren, VA. The large scale tests for fire-released carbon fibers were conducted at the US Army Dugway Proving Ground (DPG), UT.

DPG was responsible for test planning, test conduct, and reporting. NASA coordinated contractor efforts in conjunction with DPG-coordinated responsibilities. Project officer for the test was Mr. John H. Whiting of Artillery and Hazards Work Group, Test Operations Branch, Test Design and Analysis Division, Materiel Test Directorate, DPG. The Test Officer was Mr. Neil G. Magann, Artillery and Hazards Work Group, DPG. Dr. William A. Peterson of Data Requirements and Analysis Work Group, DPG, designed and calibrated the "Peterson" fire plume carbon fiber sampler used in the test. Test preparation and conduct support were supplied by the Technical Support Division of Materiel Test Directorate. Fiber counting data and sampler preparation were provided by the Environmental and Life Sciences Division of Materiel Test Directorate. Engineering assistance and support were contributed by Mr. Charles H. Warnecke of Artillery and Hazards Work Group, DPG. Contributors to the test in data reporting and analysis included Messrs John D. Trethewey and Gary L. Sutton of Data Requirements and Analysis Work Group, DPG. Modeling calculations for the pool fire trials were supported and accomplished by the H. E. Cramer Company, Inc., Salt Lake City, UT, under contract to DPG.

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SECTION 1. INTRODUCTION

1.1 BACKGROUND

The National Aeronautics and Space Administration (NASA) was selected by the Office of Science and Technology Policy (OSTP) to coordinate an effort to investigate and develop a national risk assessment of accidental release of carbon (graphite) fibers from civil aircraft accidents. US Army Dugway Proving Ground (DPG), UT was directed by US Army Test and Evaluation Command (TECOM), Aberdeen Proving Ground (APG), MD (Reference 1) to support NASA-Langley Research Center by conducting large-scale outdoor fire-released carbon fiber (CF) pool fire burn tests (designed to simulate aircraft accident fires and subsequent CF release). These tests were conducted to provide data to verify that the accidental CF release event chain works as postulated for CF/epoxy composite structures exposed to outdoor jet aircraft fuel (JP-4) fires.

1.2 DESCRIPTION OF MATERIEL

The test material was CF structural composite composed of T300 carbon fibers and 5208 epoxy matrix. The material was representative of aircraft structural configurations and miscellaneous plate and strip shapes. The material was arrayed on a test stand approximately 2.4 m (8 ft) above the pool fire surface. The carbon fibers released from the burning CF composite were of primary concern in the test series. Carbon fibers are electrically conductive and may cause malfunction of or damage to exposed electrical/electronic equipment. The test series was designed to assess the number and size distribution of the released fibers and the downwind dissemination of the fibers.

Appendix L contains detailed description and breakdown of weights and dimensions of all composite test material.

1.3 TEST OBJECTIVE

The test objective was to verify that the CF accidental release event chain works as postulated for CF/epoxy composite structural components exposed to outdoor jet fuel fires representative of civil aircraft accidents. The CF accidental release event chain elements evaluated were:

a. Source release

b. Plume lofting

c. Downwind deposition

1.4 SCOPE

Five pool fire burn trials (three source/dissemination and two source) were conducted during this test series. The trials were conducted at a DPG site approximately 2.3 km (1.4 mi) northwest of the intersection of Radial 32 (Centerline Road) and Zulu Road of the Downwind Grid (Figure 1). Table 1 summarizes the trials conducted.

Table 1. Summary of Trials Conducted During Carbon Fiber Pool Fire Tests.

Trial	Date (1979)	Ignition Time (MST)	Wind Speed[a] (m/sec)	Wind Direction[a] (°)
D-1[b]	26 Oct	1503:10	6.4	360
D-2[b]	31 Oct	0940:58	5.8	289
D-3[b]	9 Nov	1231:10	5.3	326
S-1[c]	15 Nov	0855:59	<1.0	Variable
S-2[c]	28 Nov	0856:58	<2.0	Variable

[a]Measurements made during burn time, at 8-m level on meteorological tower located 30-m upwind of pool fire.
[b]Source/dissemination trials.
[c]Source trials.

The trials consisted of burning approximately 45 kg (100 lb) of CF/epoxy materials in JP-4 pool fires. The JP-4 in the pool fires was contained in a 10.67-m (35-ft) diameter pit, and was 12.7-cm (5.0-in) deep in the burn pit. Each trial used approximately 11,355.0 ℓ (3000 gal) of JP-4. The burn rate of JP-4 is approximately 6 mm (0.25 in) of fuel depth per minute. The CF/epoxy composite materials were positioned on a metal stand over the fire. The stand used for the source/dissemination tests was 8.53 m (28 ft) in diameter and 2.51 m (8.2 ft) high (Figures B.2 and 0.3). The support stand used for the source trials consisted of a semi-hexagonal platform 6.7 m (22 ft) long, 3.4 m (11.2 ft) wide, and 2.1 m (6.9 ft) high (Figures B.3 and 0.37).

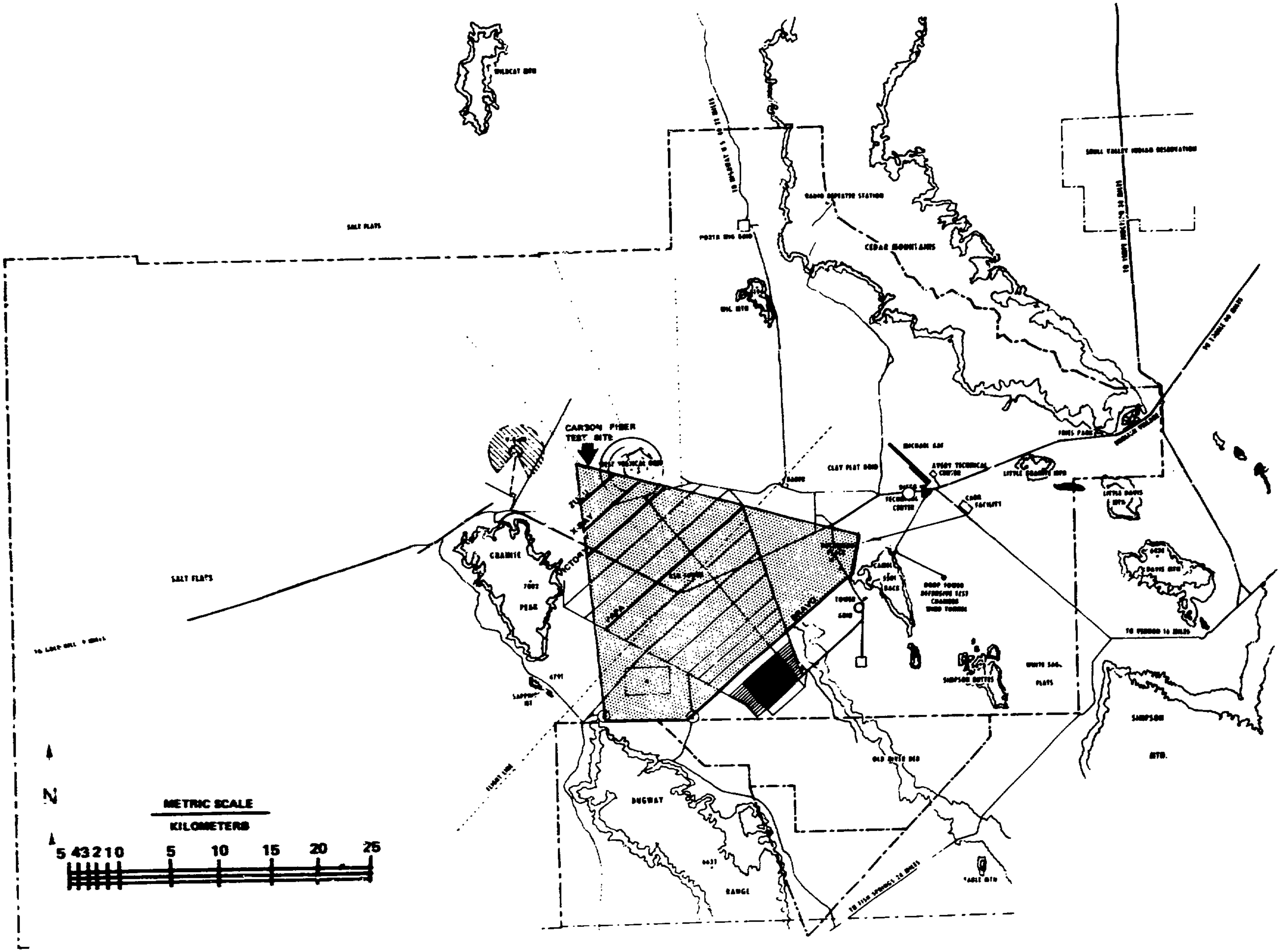

Figure 1. Carbon Fiber Test Site and Downwind Deposition Sampling Area (Shaded Area).

1.4.1 Source/Dissemination Trials

Three source/dissemination fire trials were conducted when wind speeds were 5.3 to 6.4 m/sec (11.9 to 14.3 mph) and wind direction 320 ±35°. The released CF was sampled near the source and in the rising plume. Deposition of CF was sampled downwind.

1.4.2 Source Trials

Two source fire trials [originally three in the test plan (Reference 5) changed to two by NASA] were conducted when wind speeds were almost zero. The CF were sampled above the pool fire and CF deposition was sampled in the immediate vicinity of the pool fire. The results obtained allow comparison of the influence of wind on source-release fraction.

1.4.3 Health and Safety

a. Fire-released single CF from typical structural composite materials such as T300/5208 generally ranged from a few micrometers (μm) to several millimeters (mm) in length with diameters ranging from <1 to 8 μm. Although fire-released CF may occur in the respirable range, there is no known health hazard to humans or animals from inhalation or ingestion of CF.

b. The CF were considered potentially noisome, to an unquantifiable degree. To preclude possible negative effects associated with inhalation of CF, protective clothing was required for personnel exposed to or handling CF.

c. As a minimum, personnel handling or exposed to the burned CF/epoxy composite residue were required to wear National Institute of Safety and Health (NIOSH)-approved dust respirators (effective against asbestos fibers), goggles, gloves, and coveralls. More extensive outerwear protection was required for personnel working near or downwind of the test during times that CF were released into the atmosphere.

d. The pool fire test site included a tower-supported array of suspended cables, samplers, and associated attachment hardware which was hoisted by winches located on each of the four 60.3-m (198-ft) towers. Personnel working near the fire site wore hard hats and were generally restricted from the site when the cable array was hoisted.

e. A balloon-supported net system [US Air Force Geophysics Laboratory (AFGL) and TRW] located approximately 152 m (500 ft) downwind of the fire site was used during the three source/dissemination trials.

The net system was primarily Kevlar™ cables and steel connecting hardware, such as thimbles, shackles, rings, etc. Most of the view-graph samplers (made by TRW) mounted on the net were of very low mass. However, three of the samplers, the LED (TRW), the Schrader Grid (Bionetics), and the NIOSH (NASA), weighed approximately 2.3 kg (5 lb) each. Personnel were generally restricted from operations in the immediate vicinity of the erected net. Hard hats were required for all personnel at the test site. Personnel were not permitted to cross over the net tether lines and were generally restricted from the vicinity of the lines. During the balloon inflation/deflation and tethered flight operations personnel (AFGL) were required to wear protective head gear and appropriate gloves.

1.4.4 Environmental Impact Assessment (EIA)

The environmental consequences of this test program were addressed, in general, in the DPG Installation Environmental Impact Assessment (IEIA), March 1978 (Revised July 1979) (Reference 2). More specific details of the effects on the environment were defined in the EIA for the NASA/Navy tests, March 1979 (Reference 3). The conclusions in these documents were that, at the anticipated release levels, these tests would not adversely influence the DPG environment.

SECTION 2. DETAILS OF TEST

2.1 TEST SITE LOCATION AND TEST PROCEDURES

2.1.1 Test Site Location

The trials were conducted on grid coordinates UV1094352485 (nearest meter), US Geological Survey Map Sheet No. 3363II NW, Series V897, Dugway Proving Ground, UT [2.3 km (1.4 mi) northwest of the intersection of Zulu Road and the centerline (Radial 32 of Downwind Grid)]. The azimuth of the centerline was 319°13'28.802". Distance from the center of the north JP-4 pool fire pit to Bravo Road was 19.1 km (11.86 mi). Figure 1 shows the location of the test grid.

2.1.2 Data Acquistion Procedures

During the five JP-4 pool fire trials (three source/dissemination and two source) several types of samplers were used to capture CF released to the atmosphere when CF/epoxy composite materials were burned in the pool fires. Numbers of CF and measurements (length and diameter) were determined for the CF collected by the samplers. Analyses of this fiber count data were used to determine source strengths for single fibers and clumps of fibers released into the fire plume from the burning CF/epoxy composite material. Table 2 contains the sampler requirements and types used for each trial. Appendix B includes detailed diagrams of placement of the DPG samplers.

2.1.2.1 Samplers

a. Radial and Downwind. DPG nylon mesh-type samplers (Figure 2) were used to sample the carbon fibers released from burning the CF/epoxy composite material in the pool fire. The total number of single fibers on each sampler was counted separately. Clumps of CF material on each sampler were counted separately and an estimate made of the number of fibers in each clump. The mesh sampler consisted of a standard wax-coated paperboard cylindrical container 2 mm (0.08 in) thick, 6.35 cm (2.5 in) high, and 8.57 cm (3.37 in) in diameter. Nylon mesh consisting of approximately 17 monofilaments per 2.5 cm (1 in) is stretched across one open end and fastened with kraft adhesive paper tape to provide an exposed area of 56.8 cm^2 (8.8 in^2). To ensure adhesion of fibers to the sampler, the mesh is dipcoated in a mixture consisting of 3 percent lanolin and 4 percent mineral oil in a freon 113 base. A wax-coated paperboard cover was placed over the mesh to protect the sampler from contamination before exposure. The cover was removed before the pool fire and replaced after exposure. Samplers were discarded after one use.

b. Vertical Downwind Mesh Sampler. DPG stainless steel mesh samplers (Figure 3) were used on the vertical array approximately 58.5 m (192 ft) downwind of the center of the northern-most pool fire pit. The

Table 2. Summary of Sampler Requirements for Fire-Released Carbon Fiber Pool Fire Trials.

Samplers	D-1[a]	D-2	D-3	S-1[b]	S-2
Tower-Supported (DPG)					
DPG Stainless Steel Mesh	221	221	221	-[c]	-
DPG "Peterson"	61	61	61	61	61
Stainless Steel Mesh/"Peterson"	-	-	-	122	122
Ground-Supported (DPG)					
DPG Nylon Mesh	833	833	833	100	100
Sticky Paper	464	464	464	100	100
Roto-Rod	15	15	15	0	0
Time Concentration	10	10	10	0	0
Jacob's Ladder Supported (NASA/TRW)[e]					
Mesh View Graph	420	420	420	-[d]	-
Mesh Can	95	95	95	-	-
NASA Cardboard/"Peterson"	30	30	30	-	-
NIOSH Millipore™	10	10	10	-	-
LED	2	2	2	-	-
Schrader High Voltage Grid	8	8	8	-	-

[a]Trials D-1, D-2, and D-3 were source/dissemination trials conducted at the north burn pit.
[b]Trials S-1 and S-2 were source trials conducted at the center burn pit.
[c]Sampler not used.
[d]Jacob's Ladder was not used for source trials.
[e]Test data to be analyzed by NASA/TRW (Reference 9).

Figure 2. DPG Nylon Mesh-type Cardboard Cylinder Sampler.

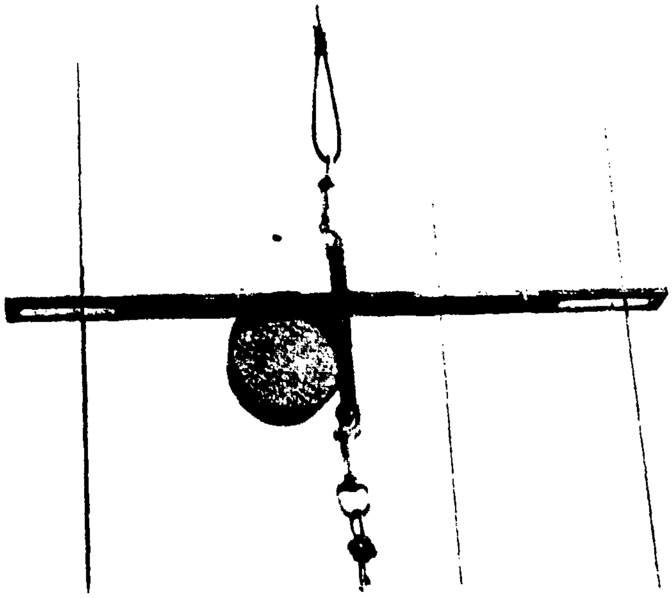

Figure 3. DPG Stainless Steel Mesh Sampler.

fibers were counted as described in paragraph 2.1.2.1.a. The mesh samplers consist of a standard seamless cylinder of 0.5-mm electrolytic tin plate, 5.72 cm (2.25 in) high, and 9.53 cm (3.75 in) in diameter with one edge curled. Sixteen-mesh stainless steel wire cloth [approximately 16 0.46 mm (0.018 in) diameter wires per 2.5 cm (1 in)] is stretched across the curled edge and spot-welded to the side of the cylinder, providing an exposed area of 71.4 cm^2 (11.1 in^2). A silicone grease, formulated to maintain its consistency from -240°C (-400°F) to 260°C (500°F), was coated onto the stainless steel mesh to ensure CF adhesion in the high temperatures these samplers were exposed to.

c. Sticky Paper. A sheet of plastic 0.1 mm (0.004 in) thick (Figure 4) with an adhesive area 8.25 cm x 12.7 cm (3.25 in x 5.0 in) was stapled to small sheets of heavy cardboard 9.84 cm (3.87 in) wide by 20.3 cm (8.0 in) long. Placement was directly on the ground, face up. The sticky surface was initially protected by waxed paper, which was peeled back prior to emplacement. After the sampler had been exposed, the waxed paper protector sheet was replaced to prevent damage to or degradation of the sample.

d. Time Concentration. A rectangular nylon mesh (Figure 5) 0.15 m (6.0 in) wide and 0.91 m (36 in) long, spring-powered and triggered by an air cylinder with a vacuum line connected to a solenoid valve and synchronized by a radio signal, moved past a slot 1.9 cm x 12.7 cm (0.76 in x 5.0 in) in time-incremented steps. Twenty-four steps were available, with at least the first and last steps used for control and secondary source purposes, respectively. This sampler provided a profile rather than a measure of absolute dosages of cloud fibers. These were placed near the paperboard mesh samplers. The back of the sampler is covered with a nylon mesh to preclude fibers from entering through the back of the sampler. Due to repeated malfunctions, experienced in sampler operation, the data obtained did not proved useful and therefore will not be discussed further.

e. Roto-rod. This sampler consisted of a small electric motor (Figure 6) turning a brass U-shaped square rod 3.4 mm (0.14 in) wide; the arms of the U-rod are approximately 15 cm (6 in) long and are spaced on approximately a 10-cm (4-in) radius. The brass U-rod is supported vertically above the motor by a small power takeoff shaft that rotates at about 2400 rpm. The brass U-rod is coated with an adhesive, viscous grease to assist in the capture of fibers that impact on the rotating arms of the U-rod. The roto-rod captures the entire spectrum of released fiber lengths, and it is generally used to capture fibers <1 mm long because the mesh screen sampler is not efficient in collecting the shorter lengths.

f. DPG "Peterson" Samplers. This passive-type sampler (Figure 7) was designed, fabricated, and calibrated at DPG. The sampler was designed to sample fire-released carbon fibers emitted into the plume

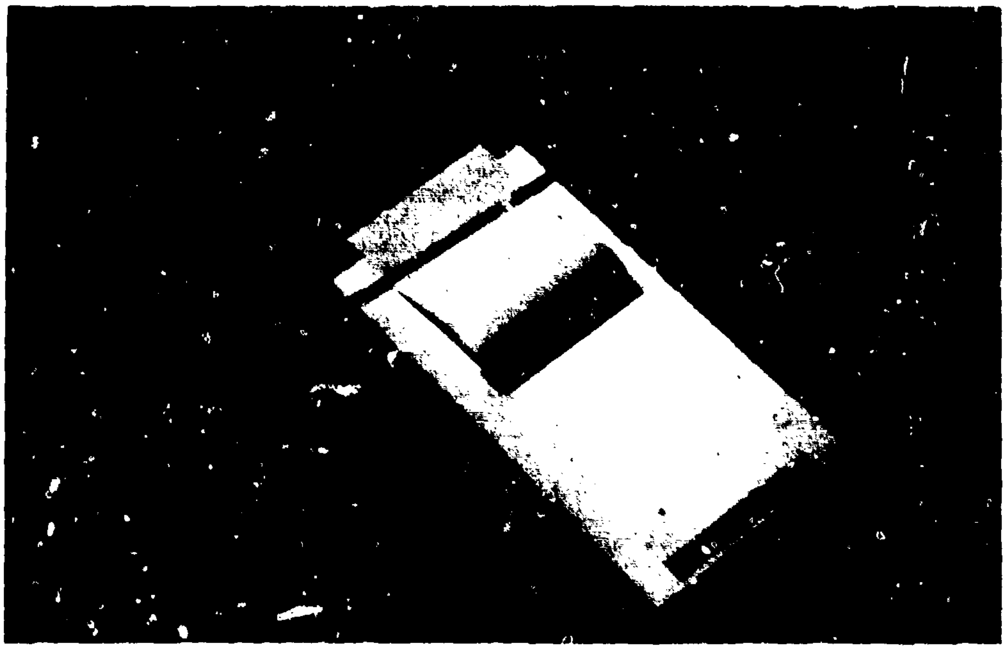

Figure 4. Sticky Paper Horizontal Sampler.

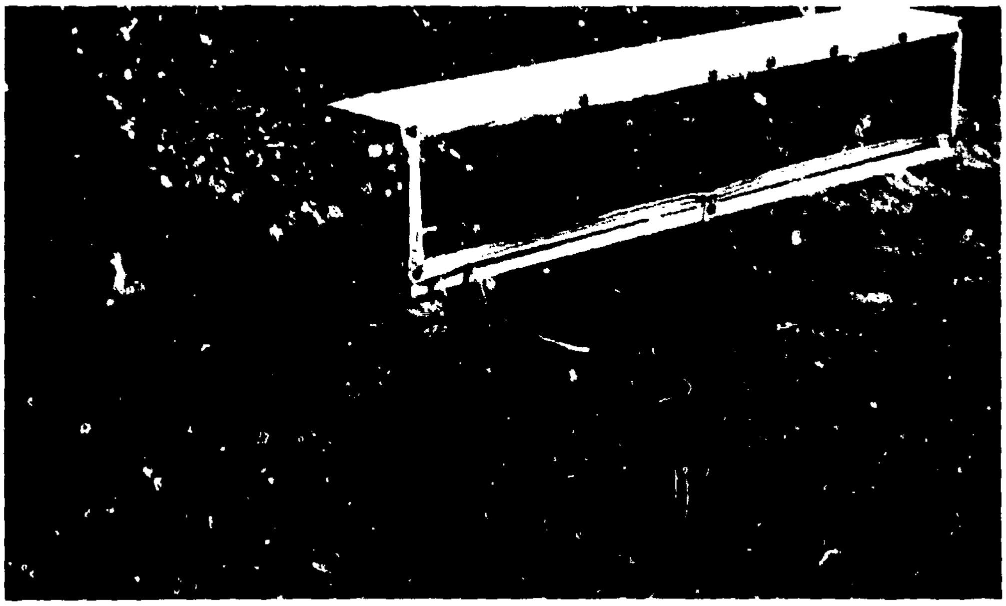

Figure 5. Time Concentration Sampler.

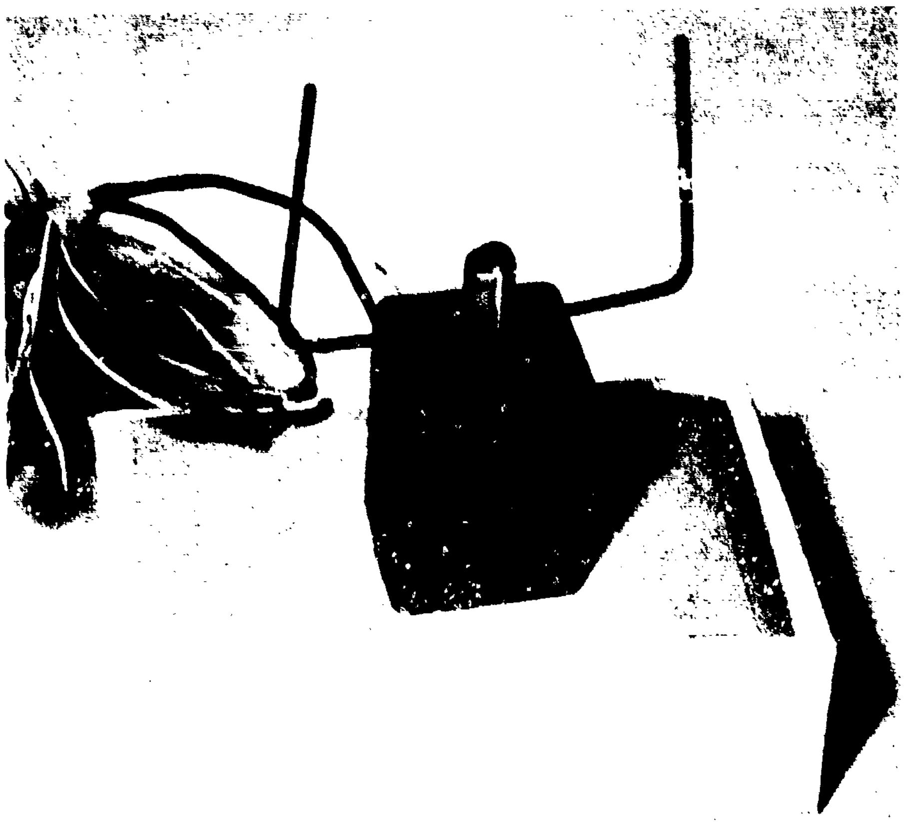

Figure 6. Roto-rod Sampler.

Figure 7. DPG "Peterson" Sampler.

from the combustion of CF material in high-temperature pool fires. The samplers trap emitted fibers as the rising plume gases and fibers enter the sampler nozzle, pass into the fiber entrapment screen where fibers of lengths greater than approximately 1 mm are retained, and the plume gases escape through the sampler exhaust.

"Peterson" samplers consist of a cylindrical 16-gauge, 1.59-cm (0.063-in), stainless steel shell which houses a cylindrical screen (Figure 8). The cylindrical shell is 25.4 cm (10 in) in diameter and 50.8 cm (20 in) long (Figure 7). It has an attached 17.8-cm (7-in) cone section which terminates on an inlet cylinder extending 3.8 cm (1.5 in) into the shell. The internal inlet attaching collar has an opening of 5.08 cm (2.0 in) in diameter. The screen section, which fits into the shell, consists of a 45.7-cm (18.0-in) long, 20.32-cm (8.0-in) diameter cylinder fabricated from 24-mesh stainless steel wire cloth [approximately 24 0.356-mm (0.014-in) diameter wires per 2.5 cm (1 in)]. One end of the screen cylinder is fitted with a solid endplate to which a 4.76-cm (1.875-in) diameter pipe is attached. The pipe extends forward 22.86 cm (9.0 in) and 7.62 cm (3.0 in) into the screen cylinder, with the last 2.5 cm (1.0 in) of the pipe flared to a diameter of 7.62 cm (3.0 in). A lid made from 24-mesh wire cloth caps the top opening of the screen. The screen section with attached pipe is placed in the outer shell and fastened into place by three setscrews imbedded in the attaching collar. A backplate cap, cut with a central opening of 7.62 cm (3.0 in), fits into the shell to complete the sampler. Appendix J is a report on the development and calibration of this sampler.

Three cables, attached to the shell, terminate in a swivel hook which was used to attach the sampler to the cable canopy array. The canopy array, with the samplers attached, was hoisted to approximately 39.6 m (130 ft) above the pool fire pit, as required.

The fibers were recovered from the entrapment screens by "air washing" (Figure 9) the screen and top into a cylindrical vacuum trap with a standard DPG nylon mesh sampler placed in the bottom outlet of the air wash. A fine (fiber impermeable) nylon mesh was placed approximately 5 cm (2.0 in) behind the standard sampler. The fibers were dislodged from the screen by the vacuum in the air wash and by blowing a gentle stream of air across all portions of the screen cylinder, pipe, and inner lid surface. After the air washing was complete, the mesh sampler was recovered and assayed in the laboratory according to the appropriate DPG MT-L SOPs for all types of DPG mesh samplers.

g. <u>Jacob's Ladder</u>. A 305-m (1000-ft) square vertical net (Figure 10) for sampling the fire plume approximately 152 m (500 ft) downwind was designed by NASA-Langley contract to TRW Corporation (Reference 9), Redondo Beach, CA. AFGL, Cambridge, MA furnished balloons and balloon-handling crews to suspend this net up to 305 m (1000 ft) above the surrounding terrain. The two balloons used to suspend the net are aerodynamically shaped 12.1 m (40 ft) in diameter by 34.8 m (100 ft) long and, when suspending the net, were approximately 488 m (1600 ft)

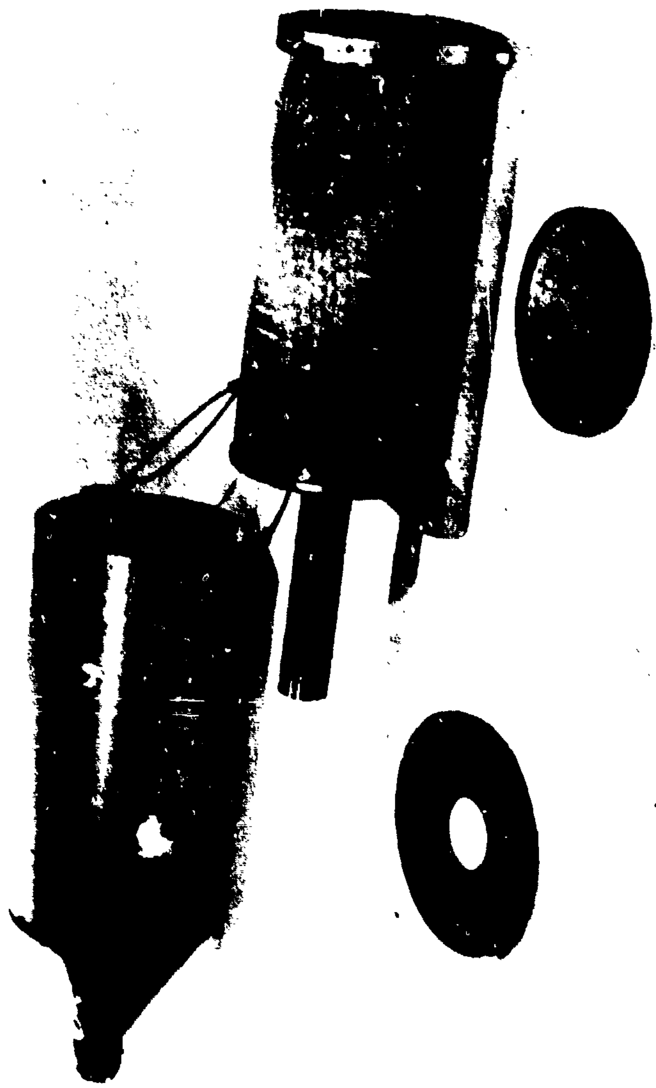

Figure 8. Disassembled DPG "Peterson" Sampler Showing Entrapment Screen, Screen Lid, and End Plate.

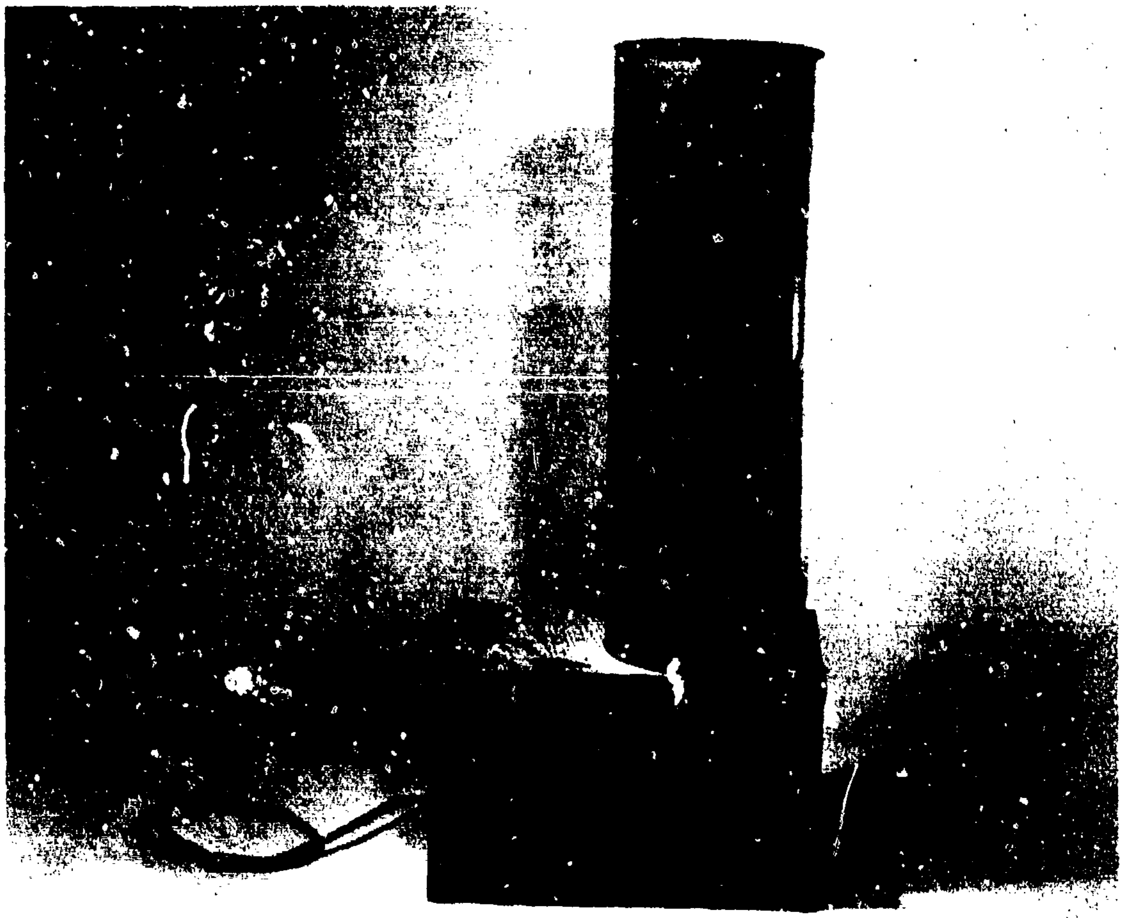

Figure 9. Carbon Fiber Recovery "Air Wash".

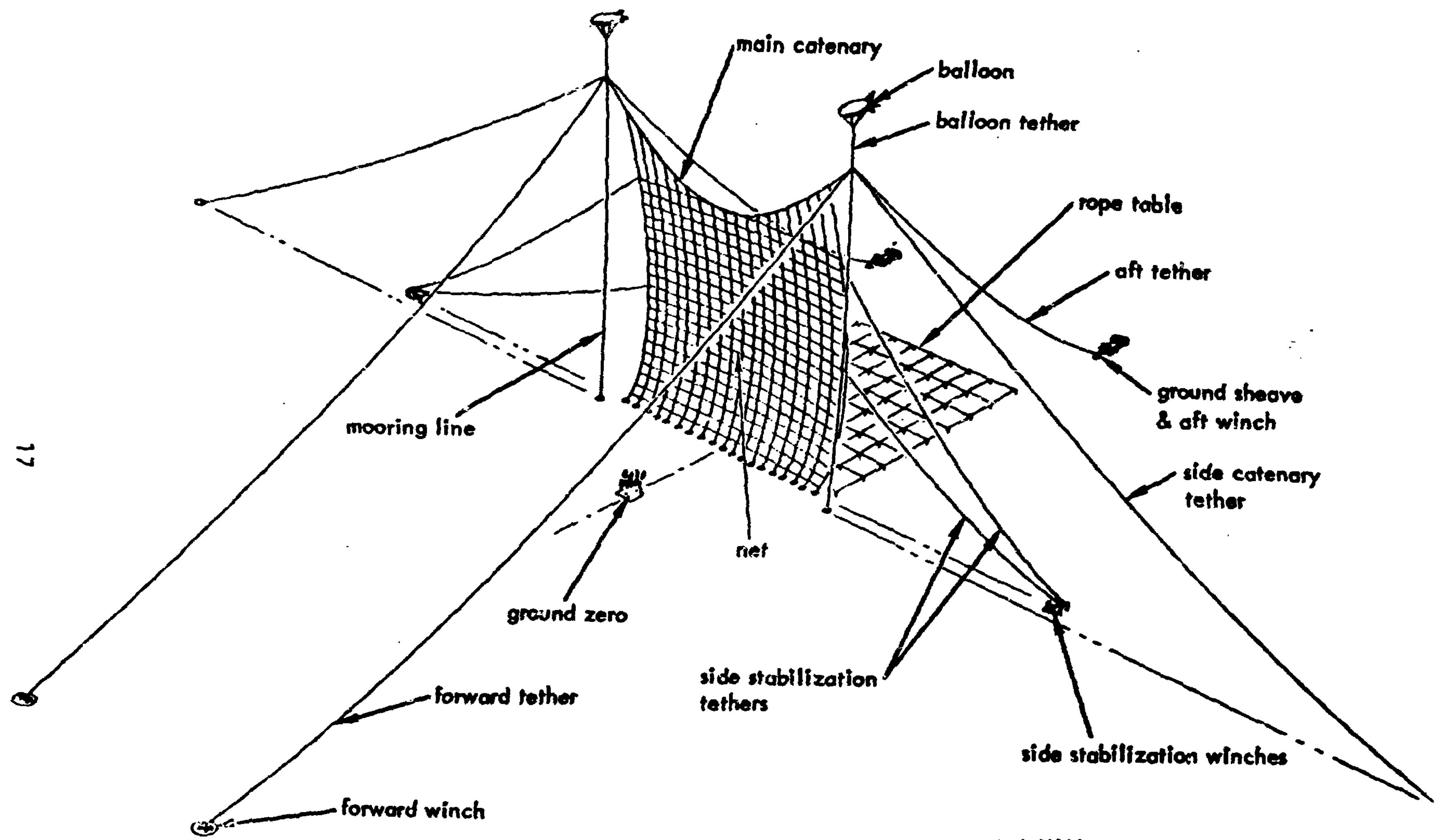

Figure 10. Sketch of NASA/TRW Jacob's Ladder Suspended With Air Force Geophysics Laboratory (AFGL) Balloons.

above the surface. Passive and active samplers were attached to the suspended net. Operation of the net array system, the collection, analysis, and reporting of the data obtained from the samplers was a NASA/TRW responsibility. However, all operational activities during the tests were coordinated with the DPG Project Officer/Test Officer and/or on-site Safety Officer.

2.1.2.2 Temperature Measurements. High-temperature thermocouples were 18-gauge wire with approximately 1.3 cm (0.5 in) of exposed chrome-alumel wire at the tip. The exposed wire was used as a heat transducer, producing a small electrical signal that indicated temperature. Response time was 100 milliseconds. Nine thermocouples were used for Trials D-1 and D-2. Two thermocouples were located at each of the four quadrants of the specimen holding table. One of the two thermocouples in each quadrant was imbedded in the CF/epoxy composite material; the second thermocouple was located adjacent to the CF/epoxy composite material. The second thermocouple measured ambient temperature. One thermocouple was located at specimen table height and attached on a central tower guy wire located approximately 3.2 m (10.4 ft) from the upwind side of the fire pool. The five ambient exposed thermocouples were shielded with a hood constructed from thin-walled, [approximately 3.2 mm (0.125 in)], stainless steel tubing 2.1 cm (.813 in) in diameter, and 4.77 cm (1.875 in) long. The tubing was slotted to enable central and perpendicular placement of the thermocouples within the hooded shield. Six additional thermocouples were imbedded in the CF/epoxy composite aircraft structure for Trial D-3. During the source trials (S-1 and S-2) two thermocouples, one in each of the two centrally located "Peterson" samplers, measured temperatures inside the samplers during the burn trials (Figures N.6 and N.11).

2.1.2.3 Meteorological Measurements and Requirements

a. Pool Fire Burns

(1) The upwind (north) meteorological measurements were taken from the 60-m meteorological tower, designated MT, located approximately 40 m due north of the pool fire site. Meteorological data recorded from this tower consisted of horizontal wind speed and temperature gradient (ΔT) at 2, 4, 8, 16, 32, 48, and 60 m; horizontal wind direction at 2, 8, 16, 32, 48, and 60 m; vertical wind direction at 16, 32, 48, and 60 m; and ambient temperature and dew point at 2 m.

(2) Downwind measurements were made on two 32-m meteorological towers (T-NO and T-SO) located 9.7 km (6 mi, T-NO) and 16.1 km (10 mi, T-SO) downwind of the pool fire sites. The towers were 3200 m from Aerial Spray Grid (ASG) center at bearings of 340° for T-NO and 140° for T-SO. The pool fire site was 12.9 km (8 mi) upwind on a bearing of 320° (Centerline Road) from the ASG Center.

(3) 30-g pilot balloons (PIBALs) with mobile observing stations were used to make observations at each of the following locations:

(a) West Vertical RAWINSONDE Site, located on the Vertical Grid 4.8 km (3 mi) downwind and 4.8 km (3 mi) east of Centerline Road.

(b) ASG, 12.9 km (8 mi) downrange on Centerline Road.

(c) Target S Grid, 20.9 km (13 mi) downrange on Centerline Road.

All three sites were used during the source/dissemination trials (D-1, D-2, and D-3). Only the West Vertical RAWINSONDE Site was used during the source trials (S-1 and S-2).

b. AFGL/NASA Balloon Operation. Meteorological observations were recorded during inflation and deflation operations and when the balloons were moored (net down). The upwind (north) tower (MT) was operated during balloon inflation and deflation operations. PIBAL and surface observations were taken every half hour when a balloon was being deployed, deflated, or moored.

c. The meteorological limitations given in DPG-TP-20-301 (Reference 5) were carefully monitored, recorded, and limiting parameters maintained throughout all operational phases of the pool fire burn trials and balloon operations (Appendix A).

2.1.2.4 Photographic Requirements and Measurements. Photogrammetric techniques were used to record the fixed tower array exposure during the pool fire burn tests and to compute plume rise. Complete documentary coverage was obtained via still, motion picture, and color video tape recording cameras. The optical coverage and camera placement requirements used for the trials are given on p. A-14 and in Figures I.1 and I.2.

a. Pool Fire Pits. The pool fire pits were two 10.67-m (35-ft) diameter, 20.3-cm (8-in) deep pits. The outer surface of the concrete-lined pits was even with the surrounding soil. The inner wall of the pits was lined with 1.59-mm (16-gauge) steel backed with concrete and embedded in the concrete pit floor. The pool fire pits were designed to accomodate 7.6 cm (3.0 in) of water and 12.7 cm (5.0 in) of JP-4. The pool fire pit centers were aligned on the grid azimuth and separated by 25.6 m (85 ft). The center (south) pit was at the center of four 60.3-m (198-ft) towers. The center of the pit was 45.7 m (150 ft) from the tower bases. The pool fire pits are shown in Figure M.8.

b. Fire Ignition System. The ignition system for the JP-4 was six flares, ss-11 pyrotechnic tracer, with a burn time of about 20 seconds. The flares were mounted on steel rods sunk into the pit,

located at the corners of a 3-m hexagon inscribed about the center of the pool. Each pair of flares was fired in series, with the three pairs then wired in parallel to the activation circuit (a 110 V generator). The circuit was shunted during the filling of the pool. The flares were taped to the steel rods, no farther than 5.08 cm (2 in) above the level of the JP-4, and were emplaced before the JP-4 was pumped into the pool (Figures N.7 and O.54).

2.2 TEST OBJECTIVE

To verify that the CF accidental release event chain works as postulated for CF/epoxy composite structural components exposed to outdoor jet fuel fires representative of civil aircraft accidents. The CF accidental release event chain elements evaluated in this test series were:

a. Source release

b. Plume lofting

c. Downwind deposition

2.3 TEST RESULTS

2.3.1 General Trial Information

Five trials were conducted to estimate cloud characteristics of CF released from CF/epoxy material burned in JP-4 fires. During each of the five trials the JP-4 was pumped into the fire pool at a delivery rate of 1514 ℓ (400 gal) per minute. The total time required to deliver the quantity of fuel was approximately eight minutes. This provided approximately 12.7 cm (5 in) of fuel overlaying approximately 7.6 cm (3 in) of water.

The first three trials (D-1, D-2, and D-3) were conducted under meteorological conditions which controlled, within limits, the bending of the resultant plume and the direction of travel of the released CF. The balloon-supported Jacob's Ladder was deployed during these trials. On each of the source/dissemination trials the gradual fuel burnout concentrated in the downwind side of the pool. During the burnout time of three to five minutes, the flames did not envelop the test specimens and the time was not considered as part of the recorded burn time. A fine mist of water was sprayed over the burned CF/epoxy composite material after the flame burned out to prevent residual burning of the composite (Trials D-1 and D-2 only).

The last two trials (S-1 and S-2) were conducted under calm meteorological conditions. Wind speeds and directions were light and variable, causing the plume rise from the fire to be almost vertical. Table 3 is a summary of operational parameters of the burn trials. Burnout time observed for the source trials was more rapid than that for source/dissemination trials.

Table 3. Summary of Operational Parameters for Carbon Fiber Pool Fire (Burn) Trials.

Trial	Date (1979)	Fuel Used (ℓ)	Ignition Time (MST)	Flame Out (MST)	Burn Time (min)	Elapsed Time Fuel Pumped and Ignition (min)	Height of Overhead Array (m)	Weight of Test Composite (kg)	Wind Speed (average) 8-m level (m/sec)	Wind Direction (average) 8-m level (°)
D-1	26 Oct	11367.6	1503:10	1522	18.9	240	30.5	46.20	6.4	360
D-2	31 Oct	11386.5	0940:58	1001	20.4	16	30.5	45.48	5.8	289
D-3	9 Nov	11371.4	1231:10	1254	22.9	15	24.4	70.77	5.3	326
S-1	15 Nov	11367.6	0855:59	0924	28.4	28	30.5	48.58	<1.0	Variable
S-2	28 Nov	11386.5	0856.58	0922	25.4	32	22.9[a]	45.55	<2.0	Variable

[a] Overhead array was raised to 34.7 m approximately 15 minutes after ignition.

During source Trails S-1 and S-2 (designed to be burned during nearly zero wind speed), only the overhead canopy sampler array was used to sample CF in the fire plume. The overhead cable array included two stainless steel mesh samplers attached to each of 61 "Peterson" samplers (Figure E.3). The balloon-supported Jacob's Ladder fielded by NASA/TRW and flown by AFGL was not used for these trials. The only ground samplers were on sampling Arc AA. During Trials S-1 and S-2, two thermocouples were located in "Peterson" samplers (Figure N.11). Wind speed averaged <1.0 m/sec with variable direction.

A helicopter (used on Trials D-3 and S-1) provided aerial support for photographic documentation by means of still, motion picture, and video tape recording cameras.

2.3.1.1 Source/Dissemination Trials

a. Trial D-1. The first pool fire trial was conducted on 26 October 1979 with ignition (Z time) at 1503.10 MST. Sixteen CF/epoxy components with a total weight of 46.2 kg (101.9 lb) were burned over the 10.7-m (35-ft) diameter pool fire. The fire pool contained 11367.6 ℓ (3003 gal) of JP-4. During this trial the test specimen support stand was centrally located within the north fire pool. The sixteen test specimens were uniformly distributed around the entire surface of the support stand (Figure K.1). Specimen description and dimensions are given in Table L.1. Meteorological conditions at the time of fire ignition consisted of average wind speeds of 6.4 m/sec with an average wind direction of 360°. Because of unfavorable wind directions, approximately four hours elapsed between the time that the fuel was pumped into the pool and ignition time. After a good fuel ignition, a well-developed heavy smoke cloud plume traveled through the right side (looking downwind) of vertical sampler lines eight through thirteen and upward through the forward "Peterson" samplers. The "Peterson" samplers were positioned 30.5 m (100 ft) above the pool fire. The cloud appeared to be concentrated on the west edge of the downwind samplers. Downwind wind speed and direction, trending to the southeast, caused the cloud travel to shift centrally onto the grid as it passed over the downwind sampling lines (10° either side of center line only at Papa, all others were on the right side only). Because of mechanical problems encountered in raising the cable array (support for "Peterson" samplers), six samplers were dropped to the ground and four hung vertically along two of the supporting cables. The total burn time was nineteen minutes.

Meteorological conditions, combined with the thermal energy released by the fire, resulted in a fire plume which was tilted approximately 67° from vertical (Figures O.6 and O.7). Much of the fire was blown under the downwind side of the specimen support stand and many of the composite specimens were only slightly burned, primarily by radiation from the flames (Table L.1).

b. Trial D-2. This trial was conducted on 31 October 1979 with ignition at 0940.58 MST. Twenty-three CF/epoxy test specimens weighing a total of 45.48 kg (100.3 lb) were positioned on the test stand. Based on the observed inclination of the fire in Trial D-1, the composite specimens were concentrated on the downwind side of the support stand (Figure K.10) with only a few scattered around the upwind region. The support stand was again centrally located within the fire pool, but had been rotated 120° to minimize the cumulative effects of heat distortion. This burn trial used 11386.4 ℓ (3008 gal) of JP-4. Meteorological conditions at ignition time were an average 5.8 m/sec wind speed and an average wind direction of 289°. Sixteen minutes elapsed between the end of fuel pump time and ignition. Fuel ignition resulted in a good burn and a dense plume which passed through the downwind center and left (looking downwind) quadrant of the "Peterson" samplers. The cloud passed through vertical sampler lines one through seven. Cloud travel stayed within the downrange sampling area. The "Peterson" sampler array was positioned at a height of 30.5 m (100 ft). Burn time was 20 minutes. The fire plume was tilted approximatly 64° from vertical (Figures 0.18 and 0.19); much of the fire was blown under the downwind side of the specimen support stand. However, because the specimens had been concentrated toward the downwind side, a greater number were severely burned (Table L.2) than in Trial D-1.

c. Trial D-3. The third test was conducted on 9 November 1979. Ignition was at 1231.10 MST. The test specimens used for this trial were left and right horizontal stabilizers from a crashed F-16 and two composite exterior structural surface panels from an F-16 vertical stabilizer. For Trial D-3, the specimen test stand was positioned in the north fire pit with the upwind (back) side of the specimen table located centrally in the fire pit, the downwind half (front) extending outside of the pit, and the entire stand had been rotated another 120° to spread the effects of head distortion. The vertical stabilizer plates were braced together, forming an inverted V, and placed on the test stand with the larger tapered end pointing downwind. On either side of the raised vertical stablizers, the right and left horizontal stabilizers were placed flat on the specimen stand, with the opposing bases adjacent to the vertical plates (Figures K.20 and 0.24). Portions of these stabilizers had evidence of mechanical fracture and burn damage caused by the fire resulting from the crash of the F-16. The total initial weight of the composite portions of the test structures was 70.77 kg (156.0 lb). This trial burned 11371.4 ℓ (3004 gal) of JP-4.

Meterological conditions at ignition time were an average 5.3-m/sec wind speed and an average wind direction of 326°. During the initial burn time the winds shifted slightly east of the 320° center line and then stabilized at an average of 326° for the duration of the burn. At about seven minutes into the burn, thermal weakening caused the specimen table support stand to collapse, lowering the test specimens to about 0.76 m (2.5 ft) above the fire pool.

Only 15 minutes elapsed between the time that the JP-4 was pumped into the pool and ignition. After ignition, a good burn developed. A dense smoke plume which, except for a very brief period when it extended slightly beyond the west tower, passed through the vertical array. The plume that passed through the overhead "Peterson" samplers [positioned at 24.4 m (80 ft) above the fire pool], appeared to "break" downward, and remained within the top samplers on the vertical array. The fire plume was tilted approximatly 62° from vertical (Figures I.28 and I.32). The total burn time was 23 minutes. Still and video cameras (in a helicopter) were used to document this trial.

2.3.1.2 Source Trials

a. Trial S-1. This was the first source trial and was conducted on 15 November 1979. Ignition was at 0855.59 MST. Eleven CF/epoxy components with a total weight of 48.58 kg (107.1 lb) were burned over the center of the 10.7-m (35-ft) diameter fire pool (center). A new test specimen support stand (Figure B.3) was built to replace the stand which had collapsed in the previous trial, D-3. Test specimens were placed uniformly over the surface of the stand as shown in Figure K.34 and described in Table L.4. The pool contained 11367.6 ℓ (3003 gal) of JP-4. Wind speed averaged <1.0 m/sec with variable direction.

Less than 28 minutes elapsed between pumping JP-4 into the pool and ignition. Upon ignition the rapidly-developed fire plume rose in a well-contained column until the soot plume failed to penetrate the temperature inversion layer. The plume rose to an inversion layer (approximately 1839 m) and stratified along that layer, traveling northwest. The plume intersected the overhead canopy array positioned at 30.5 m (100 ft). The plume column rose through the samplers in the central portion of the array. Total burn time was 28 minutes.

b. Trails S-2 was the last source trial and completed the burn trials required for this test series. The trial was conducted on 28 November 1979, with ignition at 0856:58 MST. Twenty-two test specimens with a combined weight of 45.55 kg (100.4 lb) were positioned over the fire pool (Figure K.44) and burned. Included in this material were eight 30.48-cm (12-in) square 0.64-cm (0.25-in) thick plates. The plates were positioned on the test stand as shown in Figure 0.53. Each of two plates were positioned so that a horizontal and vertical plate were placed together. Two plates were positioned on an added steel stand located approximately 1.2 m off center and only 0.5 m above the pool surface (Figures B.3 and 0.55).

The amount of JP-4 used for this trial was 11386.5 ℓ (3008 gal). The elapsed time between pumping the fuel and ignition was 32 minutes. Average wind speed ranged under 2.0 m/sec with slight variability in direction. At fire time the predicted wind speed was between 2 and 3 m/sec. Prior to fire time the overhead sampling array was lowered to 22.9 m (75 ft). However, at about two minutes into the burn the wind

speed decreased below 2 m/sec and the plume rose in a vertical column through the overhead array. At about 15 minutes into the burn the overhead array was hoisted to 34.7 m (114 ft). The plume developed rapidly after ignition, causing the soot plume to rise vertically and intersect the overhead array. The total burn time was 25 minutes.

2.3.1.3 Trials Aborted

a. On 18 October 1979 the first source/dissemination trial was scheduled and all preparations completed for testing. Because of unfavorable meteorological conditions, wind direction at 150° and no change forecast for the day, this trial was cancelled at 1125 MST.

b. On 5 November 1979 source/dissemination Trial D-3 was scheduled and test preparation completed. However, due to wind direction at 145° and no change forecast for the day, the proposed trial was cancelled at 1245 MST.

2.3.2 Test Data Reduction

2.3.2.1 Vertical Sampler Array CF Data. DPG stainless steel mesh samplers were placed at 3.05-m (10-ft) intervals [from 1.52 m (5 ft) to 53.34 m (175 ft)] on 13 vertical support cables. The cables were separated by 5.52 m (18.1 ft) except the two end towers which were each 4.44 m (14.6 ft) from the nearest tower (Figure B.5). CF data were collected during Trials D-1, D-2, and D-3. The data were reduced to CF/m^2, taking the sampler efficiency, sampler area, wind angle, and slippage of CF through the mesh into consideration. The reduced data and method of reduction are presented in Appendix C.

2.3.2.2 Downwind CF Data. DPG nylon mesh samplers were placed on a downwind grid system ranging from Arc AA (91.4 m from the north burn pit) to Row Bravo (19,109 m from the burn pit). Single fiber data were reduced to CF/m^2 and are presented in Appendix D. Reduced data reflect correction for a slippage of 15.6 percent of the fibers through the samplers (1 to 2 mm length category), and wind angle (Reference 6). The area of the nylon mesh collecting surface was 56.75 cm^2. The length distribution of CF downwind was assumed to be the same as the length distribution of fibers measured on the vertical array. The mean wind direction at the downwind sampling rows averaged over the sampling time was used for wind angle correction.

2.3.2.3 Overhead Canopy Array. The method developed for in-plume sampling involved sampling from an overhead canopy supported by cables between four towers. Winches allowed adjustment of the height of the canopy above the ground (Figure E.1). The center of the canopy was directly over the center burn pit. The canopy dimensions, the location of the samplers within the canopy, and the associated area that each sampler represented are shown in Figures E.2 and B.4. "Peterson" samplers and DPG stainless steel mesh samplers were attached to the canopy.

"Peterson" samplers, developed and calibrated at DPG (Reference 4), were used in all trials. DPG stainless steel mesh samplers were used on the vertical array. The DPG stainless steel mesh samplers were taken from the vertical array and used on the canopy in Trials S-1 and S-2 only. Two of these mesh samplers were attached to each "Peterson" sampler (Figure E.3). All samplers attached to the canopy were suspended to sample normal to the rising plume (vertical).

2.3.2.4 Meteorological Data. Table 4 summarizes meteorological data recorded during each trial. The data are for a tower located approximately 30 m northeast of the north burn pit. Additional meteorological data are given in Appendix G. Meteorological data used for development of fiber transport model input parameters are given in Appendix H.

2.3.2.5 Estimated Fiber Source Strength for Single Fibers. Source strength for total CF released by the pool fire was estimated from the amount of fibers collected on the vertical sampling array and from the overhead canopy array (Appendices C and E). Because the entire plume was not contained within the vertical array, an estimate of the percent of the plume missing the vertical array was determined by taking into account the fiber collection distribution along and up the vertical array towers and the existing meteorological conditions. The vertical array was not used during Trials S-1 and S-2.

The total CF recovered on the vertical sampling array was calculated via the following equation (Reference 6):

$$\text{Source Strength} = \sum_{i=1}^{n} \sum_{j=1}^{m} PM_{ij} * V * W_i$$

where n = Number of vertical sampling lines

m = Number of sampling levels

PM_{ij} = Fibers/m^2 on vertical line i at level j

V = 3.048 m (samplers equally spaced on vertical lines)

W_i = Horizontal width of influence of vertical lines i (see Table C.2)

Table 4. Meteorological Data for Z to Z + 5 Minutes of the Carbon Fiber Pool Fire Trials.[a]

	Wind Speed (m/sec)		Wind Direction (°)		Temp (°C)	Humidity (%)
Trial	2-m Level	60-m Level	2-m Level	60-m Level		
D-1	5.7	8.1	350	345	15.6	39
D-2	5.2	5.9	300	289	3.9	77
D-3	4.7	6.2	320	319	10.2	40
S-1	0.3	1.3	ND[b]	115	-1.9	75
S-2	0.9	2.2	351	311	-8.7	80

[a]Data are for a tower 30 m north of north burn pit.
[b]ND - no data

The following relation was used to compute the estimated source strength for the overhead canopy array.

$$\text{Source Strength} = \frac{1}{aE}\sum_{i=1}^{N} n_i A_i$$

a = sampler orifice area (0.[illegible]78 m^2)

n_i = number of fibers retrieved from $i^{\underline{th}}$ sampler

A_i = area represented by $i^{\underline{th}}$ sampler

N = total number of samplers assayed

E = sampler efficiency (0.94)

On Trial D-1 the overhead canopy array broke loose from its supporting cables, therefore, an estimate of source strength was not computed for Trial D-1. The overhead canopy array and vertical array were considered separate sampling arrays; source strengths, fiber lengths and diameters, and size distributions were calculated separately. The sampling heights of the two arrays were different, allowing a portion of the plume to intercept both arrays. Because it was impossible to determine what portion of the plume was sampled twice, each grid array was analyzed separately. Table 5 is a summary of estimated source strength.

2.3.2.6 <u>Estimated Clump Size and Source Strength</u>. Clumps of single fibers were counted on the vertical DPG stainless steel mesh sampler and "Peterson" overhead array. An estimate of the number of fibers per clump size was made. The number and percentage of clumps containing various categories of numbers of single fibers are detailed in Appendices C and E for the vertical array and the overhead canopy, respectively. Percentage of the plume intercepted in the vertical array and the overhead canopy samplers for all trials were determined and the corrected data for the trials are presented in Table 6. The measured number of clumps for Trials S-1 and S-2, corrected for sampler efficiency, for the overhead canopy array ("Peterson" sampler) could be taken as an estimate of source strength because the plume was totally contained in the canopy array. Source strength estimates and measured number of clumps are summarized in Table 6.

2.3.2.7 <u>Single Fiber Length and Diameter Distributions</u>. Single fibers collected on the DPG stainless steel mesh samplers located on the vertical and overhead canopy arrays were randomly selected for measurement of length and diameter. The distributions and mean values were computed (Tables F.1 and F.2) for lengths and diameters. The mean length of

Table 5. Summary of Estimated Source Strength of Single Carbon Fibers.

Trial	Stainless Steel Vertical Array Samplers			"Peterson" Overhead Array Samplers		
	Total Number of Fibers	Percent of Cloud Missed Sampling Array (Estimate)	Total Estimated Fibers	Total Number of Fibers	Percent of Cloud Missed Sampling Array (Estimate)	Total Estimated Fibers
D - 1	5.1×10^7	67	1.5×10^8	--[a]	--	--
D - 2	10.3×10^7	50	2.1×10^8	3.9×10^8	65	11.1×10^8
D - 3	10.2×10^7	10	1.1×10^8	0.9×10^8	77	3.9×10^8
S - 1	--	--	--	2.9×10^8	0	2.9×10^8
S - 2	--	--	--	2.2×10^8	0	2.2×10^8

a - Not used on this trial.

Table 6. Summary of Source Strength Estimates of Carbon Fiber Clumps.

Trial	Stainless Steel Vertical Array Samplers			"Peterson" Overhead Array Samplers		
	Total Number of Clumps	Percent of Cloud Missed Sampling Array (Estimate)	Total Estimated Clumps	Total Number of Clumps	Percent of Cloud Missed Sampling Array (Estimate)	Total Estimated Clumps
D - 1	11.4×10^6	67	3.4×10^7	ND[b]	--[a]	--
D - 2	44.2×10^6	50	8.8×10^7	6.6×10^6	65	1.9×10^7
D - 3	14.3×10^6	10	1.6×10^7	3.2×10^6	77	1.4×10^7
S - 1	--	--	--	1.8×10^6	0	1.8×10^6
S - 2	--	--	--	7.2×10^6	0	7.2×10^6

a - Not used on this trial.
b - No data.

fibers collected on the vertical array samplers was greater than the mean length of fibers from the overhead array samplers. This difference could be due to wind transportation of longer fibers through the vertical array after the fire was extinguished.

Length distributions for fibers collected on the samplers 1.52 m (5 ft) and 53.34 m (175 ft) above ground were also computed for Trials D-1, D-2, and D-3 (Table F.3). In general, the 1.52-m level was out of the cloud plume and the mean length of fibers collected was 4.2 mm. The 53.34-m level was considered to be in the cloud plume and had a mean length of 3.2 mm of fibers collected.

Diameter and length distributions for fiber samples on Row BB for Trials D-1 and D-3 and Row AA for Trial D-2 are in Tables F.4 and F.5. Length distributions for fibers collected on samplers from downwind rows DD, FF, Z, X, V, P, and B for Trial D-3 are given in Table F.6.

Length and diameter distributions for fibers collected on the "Peterson" samplers on the overhead canopy array are given in Tables F.7 and F.8. To avoid biasing the distribution of fiber length, a ratio of the count on the fine mesh to that on the coarse mesh of the air wash system samplers was used to obtain a proportion of lengths retrieved for each sampler.

2.3.2.8 Model Prediction. Trial D-3 was the only trial in which the plume was fully contained by the tower and downwind sampling rows at all distances from the source for a model prediction comparison (Reference 8). Model calculations of fiber deposition, including comparisions of calculated versus measured fiber densities, are in Appendix H. Plume rise equations and tables showing estimated plume heights at downwind distances are also in Appendix H. Dimensions of the plume at stabilization time were determined from photographic data (Table 7).

2.3.2.9 Temperature Data. Table 8 is a summary of maximum temperatures and the initial time maximum temperature was achieved. Table 8 also gives the average temperature of the hottest thermocouple and the average of all thermocouples at the support stand during each trial. Appendix K contains details of thermocouple placement and temperature profiles recorded for each thermocouple channel (temperature versus time). Because of the expected high temperatures, the temperature reference junction design limited recording temperatures <76°C (<169°F). Also, instrument saturation limited recording temperatures >1415.3 °C (>2579.5°F).

2.3.2.10 Carbon Fiber Composite Strip Recovery Data. Strips of CF that were delaminated from the burned CF material, lofted into the fire plume and deposited on the ground, were recovered and weighed. Recovery was made by personnel searching the area near the burn site and along the downwind deposition path of the plume. During these searches all strips were picked up, placed into plastic bags, and weighed. Table 9 contains the strip recovery data. Figures 11 and 12 show strip deposition areas, based on CF recovery for the source/dissemination and source trials.

Table 7. Dimensions of Carbon Fiber Pool Fire Plume at Stabilization[a].

Trial	Stabilized Cloud Centroid Location: Downwind Distance (m)	Stabilized Cloud Centroid Location: Height (m)	Cloud Radius at Stabilization Height (m)
D - 1	2100	310	205
D - 2	1450	340	190
D - 3	1500	350	180
S - 1	0	497	200
S - 2	-107	366	190

[a]Cloud dimensions at stabilization height were highly variable throughout any trial (see Appendix I for pictorial verification as a function of time). Data in this table were measured near the midpoint or at 10 minutes into the burn. All dimensions shown can easily vary by a factor of <2 in a very short time period (<1 minute). Data in this table should be accepted with extreme caution because of the extreme variability with time.

Table 8. Summary of Temperature Data Recorded for Each Trial, Carbon Fiber Pool Fire Tests.

Trial	Maximum Temperature at any Time (°C)	Thermocouple Channel No. on which Maximum Temperature Occured	Time After Ignition at which Maximum Temperature Occured (Min)	Average Temperature During Burn[a]: Hottest Thermocouple °C	Average Temperature During Burn[a]: Hottest Thermocouple TC No.	Average Temperature During Burn[a]: Average of all Thermocouples at Support Stand (°C)
D - 1	1309.8	1	3.6	871	4	592
D - 2	1266.5	1	12.2	983	2	471
D - 3	1415.3[b]	2	5.3	820	9	659
S - 1	1415.3[b]	1	23.0	1202	1	1059
S - 2	1415.3[b]	8	1.5	1086	9	658

a - Temperatures averaged over the total reported burn time minus 1.5 min. at start and 1.5 min. at the end of burn.
b - Maximum recordable temperature, instrument saturation level.

Table 9. Carbon Fiber/Epoxy Composite Strips Lofted in Fire Plume and Deposited on Ground Downwind During Carbon Fiber Pool Fire Trials.

Trial	Approximate Number of Strips	Mass of Strips Recovered: Inside Towers (g)	Mass of Strips Recovered: Beyond Towers (g)	Mass of Strips Recovered: Total (g)	Recovered Mass (% of Initial Composite Mass)
D - 1	8500	1120	291	1411	3.1
D - 2	24200	3154	846	4000	8.8
D - 3	4600	231	532	763	1.1
S - 1	5400	479	405	884	1.8
S - 2	6200	498	528	1026	2.3

Table 10. Carbon Fiber/Epoxy Aircraft Structural Components Burned During Carbon Fiber Pool Fire Trials.

Trial	Number of Components	Composite Mass: Initial (kg)	Composite Mass: Residual (kg)	Composite Mass: Lost (kg)	Lost Mass (% Initial Mass)
D - 1	16	46.20	25.98	20.22	44
D - 2	23	45.48	15.35	30.13	66
D - 3	4	70.77	36.78	33.99	48
S - 1	11	48.58	15.89	32.69	67
S - 2	25	45.55	26.72	18.83	41

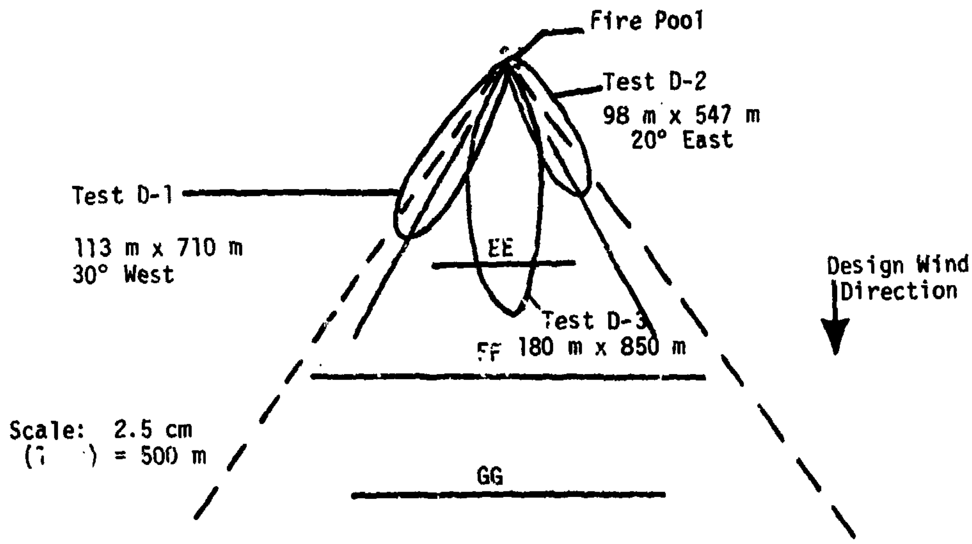

Figure 11. Ground Footprints of CF/Epoxy Composite Strip Fallout Downwind for Source/Dissemination Trials.

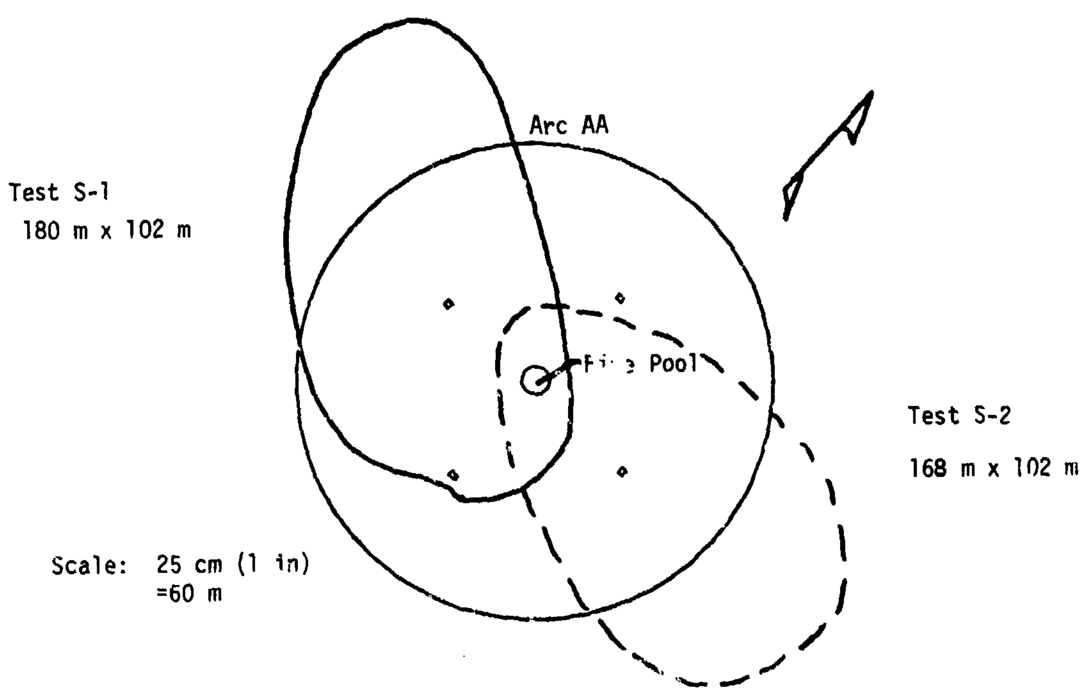

Figure 12. Ground Footprints of Composite Strip Fallout for Source Trials.

2.3.2.11 Carbon Fiber/Epoxy Components Burned and Residue Recovered. Table 10 is a summary of the CF/epoxy components burned and recovered for each trial. The composite mass is the initial mass of composite burned during each trial. The residual mass is the mass recovered after each trial. The burned residue remaining on the test stand after each trial was placed in plastic bags and weighed. The CF residue attached to metal structural cores was stripped from the core material and the CF weight recorded as a portion of the recoverable mass. The lost mass is the weight of composite mass not recovered. Appendix L includes a detailed listing of components burned and residue recovered for each trial.

2.3.2.12 Estimated Mass Recovered From Single Fibers. The estimated mass of single fibers recovered was computed by calculating the volume of a single fiber in the length distributions as shown in Table F.1., assuming an initial diameter of 8 μm. These volumes were then multiplied by the respective number of fibers in each length category and a density of 1.8 gm/cm^3 and summed over all length categories to obtain total mass recovered. An estimate of mass of carbon fibers initially present was assumed to be 70 percent of composite CF/epoxy material. A summary appears in Table 11.

2.3.2.13 Sticky Paper Sampler Data. Sticky paper samplers were placed on Arc AA for Trials S-1 and S-2, and on all sampling rows for Trials D-2 and D-3. Sticky paper samplers were not used for Arc AA on Trial D-1. The data were reduced to CF/m^2 and are given in Appendix D.

Sticky paper samplers give an indication of the location of a cloud of single fibers being transported near ground level. The amount of single fibers collected by this type of sampler gives qualatative information only and is not used to determine such data as deposition over an area; the collection efficiency of the sticky surface is unknown with respect to the surrounding terrain. For example, in an area of heavy deposition of single fibers on the ground a fiber contacting the sticky paper will remain on the paper, but, if a single fiber contacts the ground it has a good chance of becoming airborne again. Past experience in using this type of sampler to estimate deposition has shown that in an area of heavy deposition (>100 CF/m^2) the sampler can yield results which overestimate efficiency (the amount of CF actually deposited on the ground) by several hundred percent.

The sticky paper sampler results were not used for Trials D-1 and D-2 because the major portion of the single fiber cloud of airborne fibers was to the right and left of the ground sampling arrays, respectively. On Trial D-3 the sticky paper samplers verified the location of the cloud path and agreed with measured wind direction and mesh sampler data.

2.3.2.14 Rotorod Sampler. Rotorod samplers were placed on sampling Row Victory to verify and obtain additional information on exposure levels and fiber lengths. All three D trials resulted in no fiber counts from the rotorods, thus no data reduction or analysis was attempted. No counts were expected on Row Victory because of the wind direction during Trials D-1 and D-2. Trial D-3 showed a very small fiber concentration (<0.1 CF/m^3) as determined from the cardboard mesh samplers. Thus, no values for this trial were expected or obtained.

Table 11. Summary of Mass of Single Fibers Recovered During Carbon Fiber Pool Fire Trials.

Trial	Weight of Test Composite (kg)	Estimated Mass of Fibers (kg)	Estimated Number of Fibers Recovered	Estimated Mass of Fibers Recovered (kg)	Percent Mass Recovered
D - 1	46.20	32.34	1.5×10^8	0.068	0.2
D - 2	48.48	33.94	2.1×10^8	0.084	0.2
D - 3	70.77	49.54	1.1×10^8	0.052	0.1
S - 1	48.58	34.01	2.9×10^8	0.084	0.2
S - 2	45.55	31.89	2.2×10^8	0.054	0.2

SECTION 3. REFERENCES AND ABBREVIATIONS

3.1 REFERENCES

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3.2 ABBREVIATIONS

AFGL - US Air Force Geophysics Laboratory

APG - US Army Aberdeen Proving Ground, MD

ASG - Aerial Spray Grid

CF - carbon fiber(s)

℄ - center line

DPG - US Army Dugway Proving Ground, UT

EIA - environmental impact assessment

IEIA - installation EIA

JP-4 - jet aircraft fuel

NASA - National Aeronautics and Space Administration

NIOSH - National Institute of Safety and Health

OSTP - Office of Science and Technology Policy

PIBAL - pilot balloon

RADC - Rome Air Development Center, NY

RAWINSONDE - balloon-borne radiosonde

SOP - standing operating procedures

TECOM - US Army Test and Evaluation Command

Z - fire ignition time

APPENDIX A. DETAILED TEST PLAN, NASA FIRE-RELEASED CARBON FIBER TESTS

NOTE: Some portions of the original document have been removed to eliminate information that is duplicated in the body of this report or that has been superceded. Original document page numbers appear in the upper right corner of each page.

AD ______

RDTE Project No. ______

TECOM Project No. 9-CO-150-000-124

DPG Document No. DPG-TP-80-301

Test Sponsor NASA

DETAILED TEST PLAN

NASA

FIRE-RELEASED CARBON FIBER TESTS

BY

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OCTOBER 1979

U.S. ARMY DUGWAY PROVING GROUND

Dugway, Utah 84022

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* Figures deleted from this copy of the test plan.

SECTION 1. INTRODUCTION

1.1 BACKGROUND

The National Aeronautics and Space Administration (NASA) has been charged by the Office of Science and Technology Policy (OSTP) to coordinate a national effort to investigate and develop a national risk assessment of accidental release of carbon (graphite) fibers resulting from civil aircraft accidents. US Army Dugway Proving Ground (DPG), UT has been directed by US Army Test and Evaluation Command (TECOM), Aberdeen Proving Ground (APG), MD to support NASA Langley Research Center by conducting large-scale outdoor fire-released carbon fiber (CF) pool fire burn tests, designed to simulate aircraft accident fires and subsequent CF release. These tests will provide data to establish confidence that the accidental CF release event chain works as postulated for CF/epoxy composite structures exposed to outdoor jet aircraft (JP-4) fuel fires.

1.2 DESCRIPTION OF MATERIEL

The test material will be CF structural composite composed of T300/5208 fibers and epoxy matrix. The material will be arrayed on a test stand approximately 2.4 m (8 ft) above the pool fire surface. The material will be in representative aircraft structural configurations and in miscellaneous plate and strip shapes. The material released from the burning CF composite is of primary concern in the test series. The released carbon fibers are electrically conductive and may cause malfunction of or damage to exposed electrical/electronic equipment. As stated in the test objective, the test series is designed to assess the number and size distribution of the released fibers and the downwind dissemination of the fibers.

1.3 TEST OBJECTIVE

To establish confidence that the CF accidental release event chain works as postulated for CF epoxy matrix composite structural components exposed to outdoor jet fuel fires representative of civil aircraft accidents. The CF accidental release event chain elements to be evaluated in this test series are:

a. Source release fraction

b. Plume lofting

c. Downwind deposition

1.4 SCOPE (2)

Six pool fire burn tests (three source/dissemination and three source tests) will be conducted during this test series. The tests will be conducted at a site on Radial 523 (Centerline Road), approximately 2.3 km (1.4 mi) from the center of Downwind Grid. The site is northwest of Zulu Road (Figure 1). The tests, in general, will consist of exposing approximately 45 kg (100 lb) of CF epoxy materials to temperatures obtained in JP-4 pool fires. The JP-4 fuel will be 12.7 cm (5 in) deep in a 10.67 m (35 ft) diameter burn pit. Each trial will use 11355.0 ℓ (3,000 gal) of JP-4. The burn rate of JP-4 is approximately 6 mm (0.25 in) of depth per minute.

1.4.1 Source and Dissemination

Three fire tests will be conducted when wind speed is 2.7 to 5.4 m/sec (6 to 12 mph) with a wind direction of 320° ±35°. The CF release will be sampled near the source and in the rising plume. Deposition of CF will be sampled downwind.

1.4.2 Source Fires

Three fire tests will be conducted when wind speed is almost zero. The CF will be sampled just above the visible flame and deposition will be sampled in the immediate vicinity of the pool fire. Results will be compared with those of paragraph 1.4.1 to assess the influence of wind on source release fraction.

1.4.3 Health and Safety

a. Fire-released single carbon fibers from typical structural composite materials such as T300/5208 generally range from a few micrometers (μm) to several millimeters in length. For those fibers longer than 1 mm, the predominant length is approximately 2 mm. The fibers range in diameter from <1 - 8 μm. Although the fire-released fibers occur in the respirable range, there is no known health hazard to humans or animals from inhalation or ingestion (Environmental Impact Assessment, Reference 1).

b. Johns-Mansville Cereblanket™ insulation is composed of ceramic fibers that are 47 percent Al_2O_3 and 52.8 percent SiO_2 (alumina and silica, respectively). This insulation is fairly impervious to high gas velocities, even after exposure to temperatures as high as 1649°C (3000°F). However, in handling, applying, and cutting this material, very fine unmeasured particulate matter may be released in the immediate vicinity of the insulation.

NOTE: Detailed information can be found on pages 7-8 of the final report.

c. Both type of fibers are potentially noisome, to an unquantified degree. To preclude possible negative effects associated with inhalation of either type of fibers, protective clothing will be required for personnel who will be exposed to or handle carbon fibers or the ceramic insulation. (4)

d. At a minimum, personnel handling the burned CF composite residue or the insulation will wear NIOSH-approved dust respirators (effective against asbestos fibers) and gloves. More extensive outerwear protection will be required for personnel working near or downwind of the test site during times that fibers are released into the atmosphere.

e. The fire test site will consist of an array of suspended cables, samplers, and associated attachment hardware which will be hoisted by winches located on each of the four 60.3-m (198-ft) towers. Personnel working near the fire site will wear hard hats.

f. A balloon-supported net system (AFGL/NASA) will be located approximately 152 m (500 ft) downwind of the fire site. The net system is constructed primarily of Kevlar™ cables and steel connecting hardware, such as thimbles, shackles, rings, etc. Most of the view-graph samplers mounted on the net will be of very low mass. Two of the samplers, however, will weigh approximately 2.3 kg (5 lb) each. Personnel will generally be restricted from operations in the immediate vicinity of the erected net. Hard hats will be required for all personnel at the test site. Personnel will not be permitted to cross over the net tether lines and will generally be restricted from the vicinity of the lines.

Detailed safety guidelines will be given in the Safety Annex (Appendix A) of the Test Operation Procedure. The Test Safety Officer will enforce all safety requirements.

1.4.4 Environmental Impact Assessment (EIA)

The environmental consequences of this test program are addressed, in general, in the DPG Installation Environmental Impact Assessment (IEIA), March 1978 (Reference 1). More specific details of the effects on the environment were defined in the EIA for the NASA/NAVY Tests, March 1979 (Reference 2). These documents reveal that the CF epoxy material to be used in this test will be the same, the expected fiber release will be the same or less than, and the test site will be the same as in the referenced documents. The consequences of this test program will have no adverse effects on the environment at DPG.

SECTION 2. DETAILS OF TEST (5)

2.1 TEST OBJECTIVE

Objectives are detailed in paragraph 1.3

2.2 CRITERIA

None

2.3 DATA REQUIRED

The following data are required for the fire tests:

a. Pool Fire Fuel Operation.

(1) Date/time of test

(2) Time of delivery of JP-4 fuel to site

(3) Amount of JP-4 delivered (ℓ)

(4) Time required to pump JP-4 into the pool area

(5) Time of pool fire ignition

(6) Time of pool fire burnout

b. Fire Ignition System.

(1) Wire/power system

(2) Type of initiator

(3) Quantity of initiators (include placement schematic)

(4) Functional operation of each initiator

(5) Time of igniter engagement

(6) Energy output of initiators (°C and BTU)

c. Heat Measurement (Thermocouples).

(1) Make, model, and supplier of thermocouples

(2) Size and type of wire and integral insulation

(3) Number and location of thermocouples and corresponding data recorder channel

(4) Record of pretrial check-out and recording channel output for each thermocouple (6)

(5) Post-trial report of reliability, accuracy, and durability

(6) Analysis of the thermocouple measurement for each test

(7) Temperatures (°C), continuous via recorder

d. Meteorological Conditions.

(1) Temperature (°C)

(2) Temperature gradient (°C)

(3) Wind speed (±0.1 m/sec)

(4) Wind direction

(5) Atmospheric stability parameters

(6) Relative humidity (percent)

(7) Barometric pressure (mm of Hg)

(8) Precipitation

e. Photogrammetric Measurements - Record of Fire Dimensions.

(1) Maximum height of plume (m)

(2) Rise time of plume from ignition to maximum height

(3) Maximum width of plume (m)

f. Laboratory Reports. Data reports for each passive CF sampler, including method of counting and counts per sample versus grid location and type of sampler, will be submitted to the Project Officer as soon as possible after each trial.

g. Carbon Fiber Composite Test Specimen (may be individual pieces or bundles of composite materials bound together).

(1) Description of each composite material specimen

(2) Specimen identification number recorded for each test item

(3) Weight (g) of each composite test specimen prior to and after burning

(4) Sketch of composite specimen placement and location on specimen stand (7)

(5) Photographic record of each test specimen prior to and after burning

(6) Specimen number on each test sample residue storage bag (residue will be collected, weighed, and placed in plastic containers)

2.4 DATA ACQUISITION PROCEDURE

Six JP-4 pool fire tests will be conducted. Details of the pool fire location, sampling types, and number are given in Figure 1 and Appendix B. The burn pit to be used, the sampling requirements for the three source and dissemination fire tests, and the three source fire tests to be run are outlined in Table 1.

Table 1. Sampler Requirements for NASA Fire-Released Carbon Fiber Tests.

Tests (three each)	Burn Pit North	Burn Pit Center	Canopy Array DPG[a]	Down Range (mesh, TC, RR)[b]	Radial Sampling (mesh)[b]	Vertical (steel mesh)	Jacob's Ladder (NASA/TRW)
Source & Dissemination	X		X	X	X	X	X
Source		X	X		X		

a - Peterson Samplers
b - Sticky Paper Samplers

NOTE: The information in deleted paragraphs 2.4.1 and 2.4.2 is contained in paragraphs 2.1.2.1 and 2.1.2.2 of the final report.

2.4.3 Meteorological Requirements

(18)

2.4.3.1 Instrumentation Setup

a. Pool Fire Burns. The upwind (north) sampling tower will be instrumented as follows:

HT(m)	Ta	Td	ΔT	HWD	VWD	WS
2	X	X	X	X		X
4			X			X
8			X	X		X
16			X	X	X	X
32			X	X	X	X
48			X	X	X	X
60			X	X	X	X

Where: Ta is air temperature (°C)

Td is dew point temperature (°C)

ΔT is temperature (°C) difference between 0.5 m and each indicated level

HWD is horizontal wind direction (°)

VWD is vertical wind direction (°)

WS is wind speed (m/sec)

Downwind measurements of horizontal wind direction and wind speed will be made on the two 32-m towers [located 3.2 km (2 mi) uprange and 3.2 km (2 mi) downrange of the Aerial Spray Grid (ASG) tower] at the 16- and 32-m levels and at the 32- and 48-m levels on the Target S meteorological tower. Observations using 30 g Pilot balloons (PIBALS) will be taken near the meteorological towers. Surface observations will be taken at the upwind PIBAL station. All tower data will be telemetered to the Ditto Technical Area data central.

b. AFGL/NASA balloon inflation and deflation operations and when balloon is in moored status (net down).

The upwind (north) sampling tower will be operated during balloon inflation and deflation operations. PIBAL and surface observations will be taken every half hour when a balloon is being deployed or in a moored position. (19)

2.4.3.2 Meteorological Limitations for Source and Dissemination Fire Tests and Balloon Lofting Operations

a. Pool Fire Burns

(1) Wind direction at 48-m level (320° ±35°)

(2) Wind speed at 48-m level (3-6 m/sec)

(3) No thunderstorm within 48.3 km (30 mi) radius of balloon site

b. AFGL/NASA balloon inflation: wind speed at 2-m level (0-2.5 m/sec)

c. AFGL/NASA balloon up (moored): wind speed at 500-m level (0-15 m/sec)

d. AFGL/NASA balloon up (net up): wind speed at 500-m level (0-10 m/sec)

e. AFGL/NASA balloon deflation: wind speed at 2-m level (0-5 m/sec)

f. Weather alerts

(1) Surface (SFC) wind will exceed 7.5 m/sec in next 6 hours

(2) Frontal passage during next 12 hours

(3) Thunderstorm activity

(4) Any other severe weather

2.4.3.3 Meteorological Limitations for Source Fire Tests

a. Low level (Tower) winds

The mean wind speed from the surface to the height of the Peterson Samplers shall not exceed the following:

Sampler height (m)	Mean wind speed (m/sec)
25	2.5
30	2.0
35	1.5

b. Cloud transport winds

The cloud transport will be such as to avoid primary cloud travel over the north end of the Wig Mountains, Ditto Technical Center, and the north end of Granite Mountain and the Causeway. These restrictions are generally associated with transport wind directions of 200°-290° and 060°-090°.

2.4.4 Photographic Requirements (20)

Photogrammetric techniques will be used to record the fixed tower array exposure to fire and to compute the plume location, plume dimensions, and plume rise time. Complete documentary coverage using still, motion picture, and color video tape recording is also required.

2.4.4.1 Optical Coverage

a. Camera system requirements are given in Table 2.

b. Camera system 1 will be used for plume location, plume rise rate, and plume dimension computations. A frame time reference must be provided for system 1.

c. Camera system 2 (N-1, N-2, and N-3) will be used for close-up coverage of plume location, plume rise rate, and plume dimension computations. A frame time reference must be provided for system 2. In addition, NASA-supplied battery-operated clocks will be positioned within the field of view of cameras N-1 and N-2.

d. Camera system 3 (T-1 and T-2) will be used for close-up coverage of the four (200-ft) high fixed towers and their exposure to fire and plume. A frame time reference must be provided for system 3.

e. Camera system 4 will be positioned to one side of and downwind from the plane of the net at a location to provide coverage of the fire. It will be at least 1828.8 m (6000 ft) down range and at a minimum of 914.4 m (3000 ft) elevation. A frame time reference must be provided for system 4.

f. A roving photographer will provide 16-mm color motion picture coverage throughout preparation for and during the test. The photographer will be required to wear aluminized thermal protective clothing while making motion pictures of the JP-4 pool and pumping operations prior to and during the actual burn.

g. Still photography is required throughout preparation and conduct of the test. The still photographer will be required to wear aluminized thermal protective clothing while photographing of the JP-4 pool and fuel pumping operations pior to and during the actual burn.

h. Camera system 5 will use video tape for a general record of the CF test, including the fire, CF Net Sampler, towers, test site, and other test conditions.

2.4.5 Pool Fires

Each test will use approximately 11,356 ℓ (3000 gal) of JP-4 aviation fuel. The JP-4 fuel will be burned in a 10.67-m (35-ft) diameter pit with the 12.7 cm (5 in) of JP-4 floating on 10.7 cm (4 in) of water. The burn rate for JP-4 fuel is approximately 0.64 cm (0.25 in) per minute. Therefore, the expected burn time of the fire is approximately 20 minutes.

Table 2. Camera System Requirements for Fire-Released Carbon Fiber Tests.

System	Camera Type	Frame Rate	Approximate Placement	Activation Time[a]	Run Time[b]	Field of View
1	4 35 mm color	5 pps[c]	90° opposed, 1524 m (5000 ft) from pool center	Z - 30 sec	33 min	914 m (3000 ft) for plume rise
2	3 35 mm	5 pps	457.2 m (1500 ft) west, 457.2 m north, and 457.2 m northwest (N-1, N-2 and N-3) of CF Sampler	Z - 30 sec	33 min	Must include CF Net Sampler
3	2 35 mm	5 pps	76.2 m (250 ft) north (T-1 and 76.2 m west (T-2) of pool center	Z - 30 sec	33 min	Must include 4 towers and pool center
4	1 35 mm	5 pps	About 1828.8 m (6000 ft) west and about 609.6 m (2000 ft) south of CF net Sampler	Z - 30 sec	33 min	Must include fire, CF Net Sampler, and be at a minimum elevation of 914 m (3000 ft) above the surface
5	2 TV	-[d]	76.2 m (250 ft) west of pool center, or as required	Z - 30 sec	20 min	

[a]Actually on the order of the Test Officer
[b]Nominal burn time is 20 minutes; actual burn time may vary slightly
[c]pps - pictures per second
[d]Continuous operation

(21)

The 11,356 ℓ (3000 gal) of JP-4 will be transported and pumped by one 4542 ℓ (1200 gal) fuel truck and one 9084 ℓ (2400 gal) fuel truck. The fuel trucks will draw the JP-4 from Michael Army Airfield (MAAF) storage tanks the night before the test and will move to the test site two hours before the scheduled test time (0600 hours departure from MAAF). (22)

2.4.6 Fire Ignition System

The ignition system for the JP-4 fuel will be six flares, ss-11 pyrotechnic tracer, with a burn time of about 20 seconds. The flares will be mounted on steel rods sunk into the pit, located at the corners of a 3-m hexagon inscribed about the center of the pool. Each pair of flares will be wired in series, with the three pairs then wired in parallel to the activation circuit (a 110 V generator). The circuit will be shunted during the filling of the pool. The flares will be taped to the the steel rods, no farther than 5.08 cm (2 in) above the level of the JP-4, and will be emplaced before the JP-4 is pumped.

2.5 ANALYTICAL PROCEDURES

2.5.1 Source Strength

Source strength of single fibers and clumps of fibers will be computed using a point-count technique. For the three trials with a minimum wind speed of 2.7 m/sec (6 mph), the vertical array of stainless steel mesh samplers will be used to estimate source strength. The method involves determining the number of fibers per sample and factoring that value up to the appropriate representative area and summing. The formula for this estimate follows:

$$\frac{1}{c} \sum_{i=1}^{n} s_i \cdot w_i \cdot h_i$$

Where:

- n is the number of samplers
- s is a steel mesh sample value (number of fibers)
- w is the width represented by the sample (usually the horizontal distance between samplers)
- h is the height represented by the sample (usually the vertical distance between samplers)
- c is the area of the sample surface (for the stainless steel mesh sampler, 72.4 cm^2).

In the case of the three trials where calm winds are required, the Peterson Sampler will be used to estimate source strength. The formula for that estimate is the same as in the above paragraph except h_i becomes l_i (length) and the constant C changes due to a smaller air intake

opening to the large screen fiber trap. The area of the intake opening (23)
will be used as a value for C because the sampler is assumed to be isokenetic. Extreme caution will be taken in the interpretation of these data due to test inexperience with the sampler. Also, possible unknowns such as fiber loss through the screen and the influences of a turbulant regime on the sample may affect the interpretation of the data.

No data reduction or analysis is planned for the TRW Jacob's Ladder. However, if a source strength estimate is desired, the same formula as given above would apply. The constant C would change because of the view-graph sampler screen size.

The above source strength computations will be made for single fibers. For clumps of fibers the same calculations will be used to estimate the total number of clumps emitted during the fire. Size categories will then be determined for single fibers and clumps by giving consideration to the distribution of sizes in paragraphs 2.5.2.1 and 2.5.2.2.

2.5.2 Length Distribution

2.5.2.1 Single Fibers. Single fiber length distribution will be determined in 1-mm intervals beginning with 1 mm length and ending with >20 mm. Percent distribution in each category will be computed and plotted. This distribution will be determined for all trials. Extreme caution will be taken in determining this distribution from the calm wind condition trials because the Peterson Sampler is the only fiber collection device on the trials and the amount of material which may have passed through the screen trap (slippage factor) will be unknown.

2.5.2.2 Clumps. The distribution of clump sizes will be categorized by the estimated number of fibers in a clump. This distribution will start with a clump size of two fibers and end with a size of >500 fibers. At least six intervals will be chosen, depending on the frequency of occurrence of sizes. Percentage of fibers in each category will be computed and plotted.

2.5.3 Prediction Versus Measurement

For the three trials where the minimum windspeed is 2.7 m/sec, a transport and dispersion model will be used to predict dosages (exposures) downwind. These predictions will be compared to actual values of dosage measured on the downwind sampling lines. From the comparison and using past experience on similar tests, a statement of model adequacy will be attempted.

Input to the model will be:

a. Plume rise height and dimensions at stabilization

b. Meteorological parameters measured at the time of the test (24)

c. Source strength for single fibers only, as estimated from the stainless steel mesh vertical sampling array

SECTION 3. APPENDICES

APPENDIX A. CRITICAL ISSUES, OTHER ISSUES, AND TEST CRITERIA

PART 1. CRITICAL ISSUES

NONE

PART 2. OTHER ISSUES

NONE

PART 3. TEST CRITERIA

NONE

NOTE: Appendix B, Site Layout, is Final Report Appendix B, Figures B-1 through B-10.

APPENDIX C. SUPPORT REQUIREMENTS

(C-1)

1. US Army Dugway Proving Ground will supply the following:

   a. Test grid, pool fire site construction, test support preparation, and required electrical power.

   b. Meteorological instrumentation and meteorological support.

   c. Fuel for the pool fires, vehicles, generators, and winch motors. Anticipated fuel needs for the test are 68,130 ℓ (18,000 gal) of JP-4, 760 ℓ (200 gal) of diesel fuel, and 1520 ℓ (400 gal) of gasoline.

   d. Samplers and sampler support for canopy, vertical grid, and downwind dissemination samplers.

   e. Sampler preparation, assay, and required data reduction and analysis.

   f. Project, operational control, and testing coordination.

2. NASA/TRW will supply the following:

   a. Design, construction, and field the Jacob's Ladder and associated passive and active samplers.

   b. Passive and active samplers for the Jacob's Ladder.

   c. Jacob's Ladder sampler preparation, sample assay, data reduction, and reporting.

   d. Jacob's Ladder fielding, direction, and control.

   e. Required support personnel.

3. AFGL will supply the following:

   a. Balloons and balloon winches with all equipment necessary for balloon lofting.

   b. Required personnel for operational conduct and support.

APPENDIX D. TEST SCHEDULE

(D-1)

The six pool fire tests are expected to require eight weeks to complete.

The three source and dissemination fire tests will be the first series of tests to be conducted. They are scheduled to begin the fourth week in October 1979 and be completed the second week in November 1979.

The three source fires tests will begin after the source and dissemination fire tests, with expected completion by the end of November 1979.

APPENDIX E. REFERENCES (E-1)

1. US Army Dugway Proving Ground, Dugway, UT 84022, Installation Environmental Impact Assessment, March 1978.

2. US Army Dugway Proving Ground, Dugway, UT 84022, Environmental Impact Assessment (EIA) for Navy/NASA Coordinated HAVE NAME Effort JTCG Subgroup 6, TECOM Project No. 8-CO-150-000-036, March 1979.

APPENDIX F. INFORMAL COORDINATION

(F-1)

This Detailed Test Plan has been developed in conjunction with and has been fully coordinated with the test sponsor, NASA. The provisions of the plan fully meet the requirements of the test.

Richard A. Pride

RICHARD A. PRIDE
NASA Test Manager

NOTE: Appendix G, Distribution List, has been deleted.

APPENDIX B. DETAILS OF SITE LAYOUT REQUIREMENTS

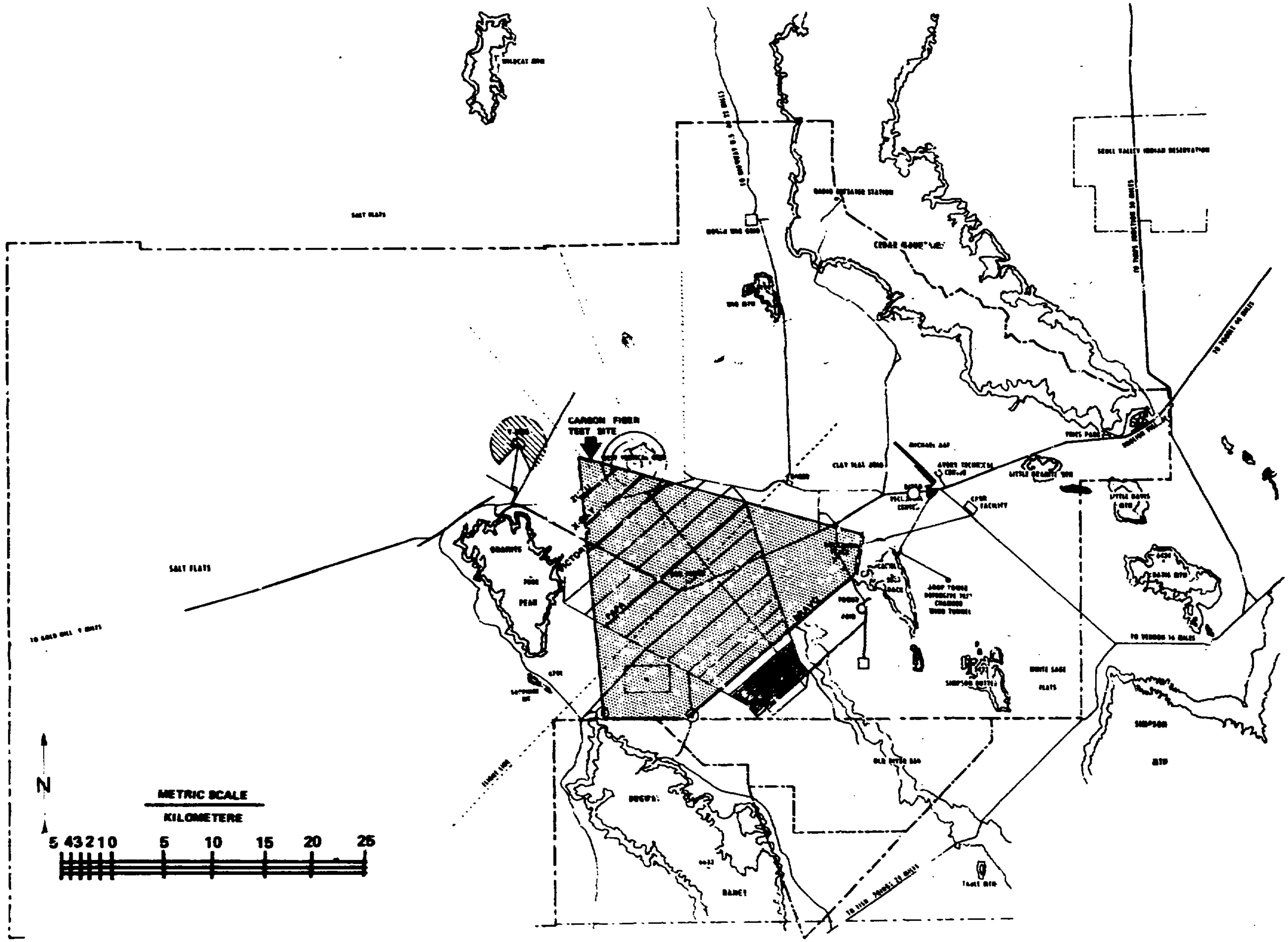

Figure B.1. Carbon Fiber Test Site and Downwind Deposition Sampling Area (Shaded Area).

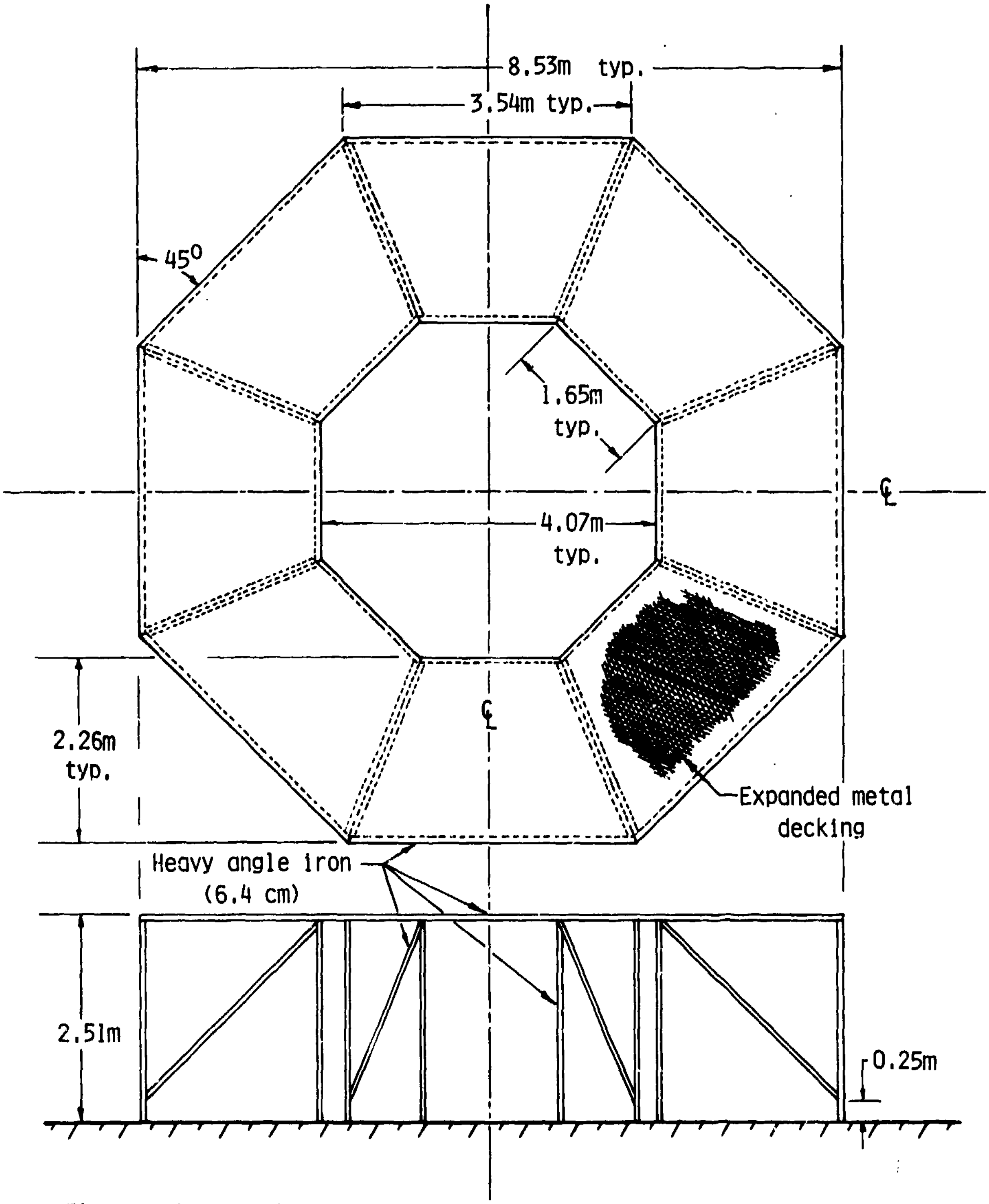

Figure B.2. Specimen Support Stand Utilized for Carbon Fiber Pool Fire Test, Trials D-1, D-2 and D-3.

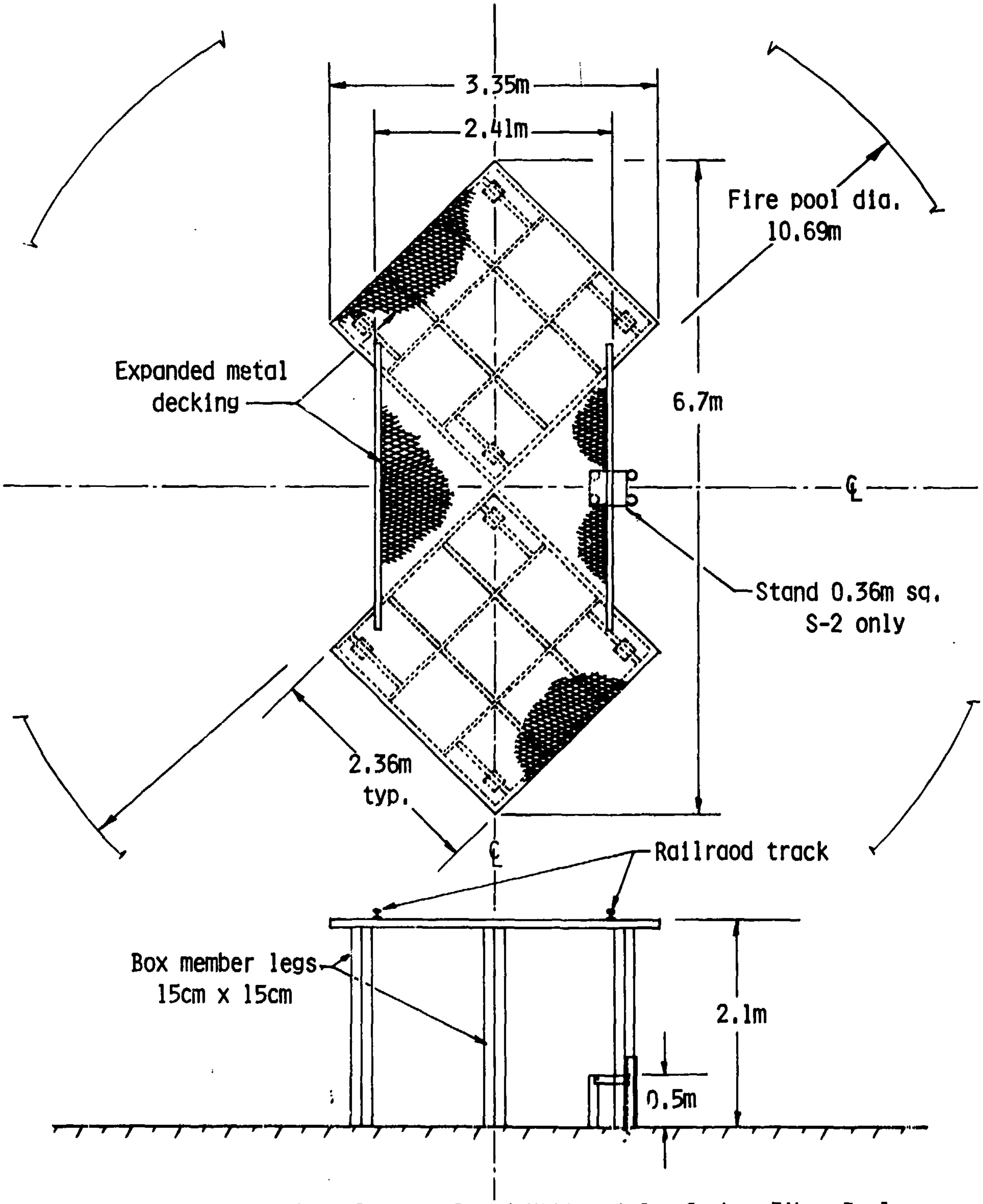

Figure B.3. Specimen Support Stand Utilized for Carbon Fiber Pool Fire Test, Trials S-1 and S-2.

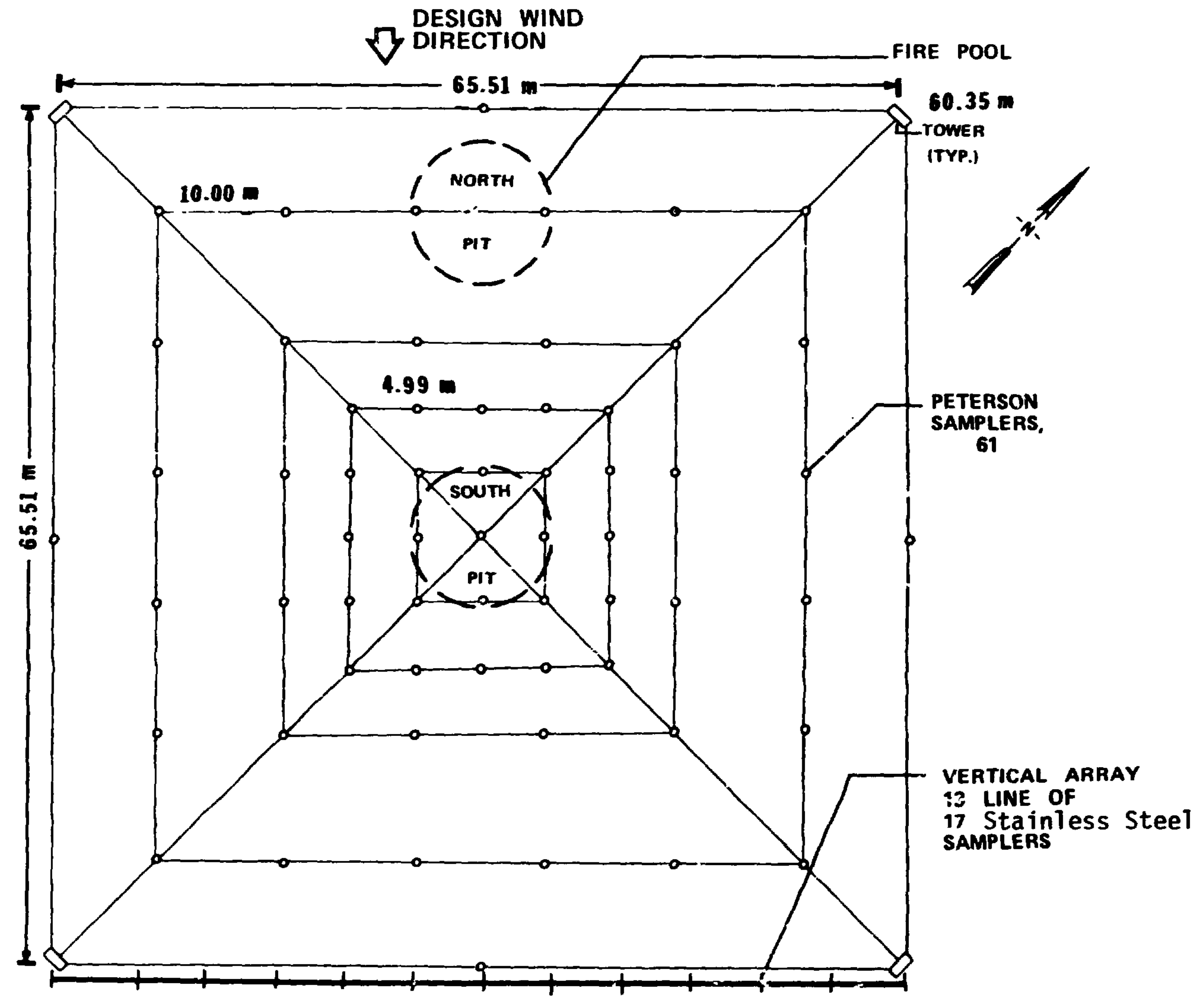

Figure B.4. Carbon Fiber Burn Test Site, Showing Tower-Supported Overhead Canopy Array, "Peterson" Sampler Locations, and Vertical Array.

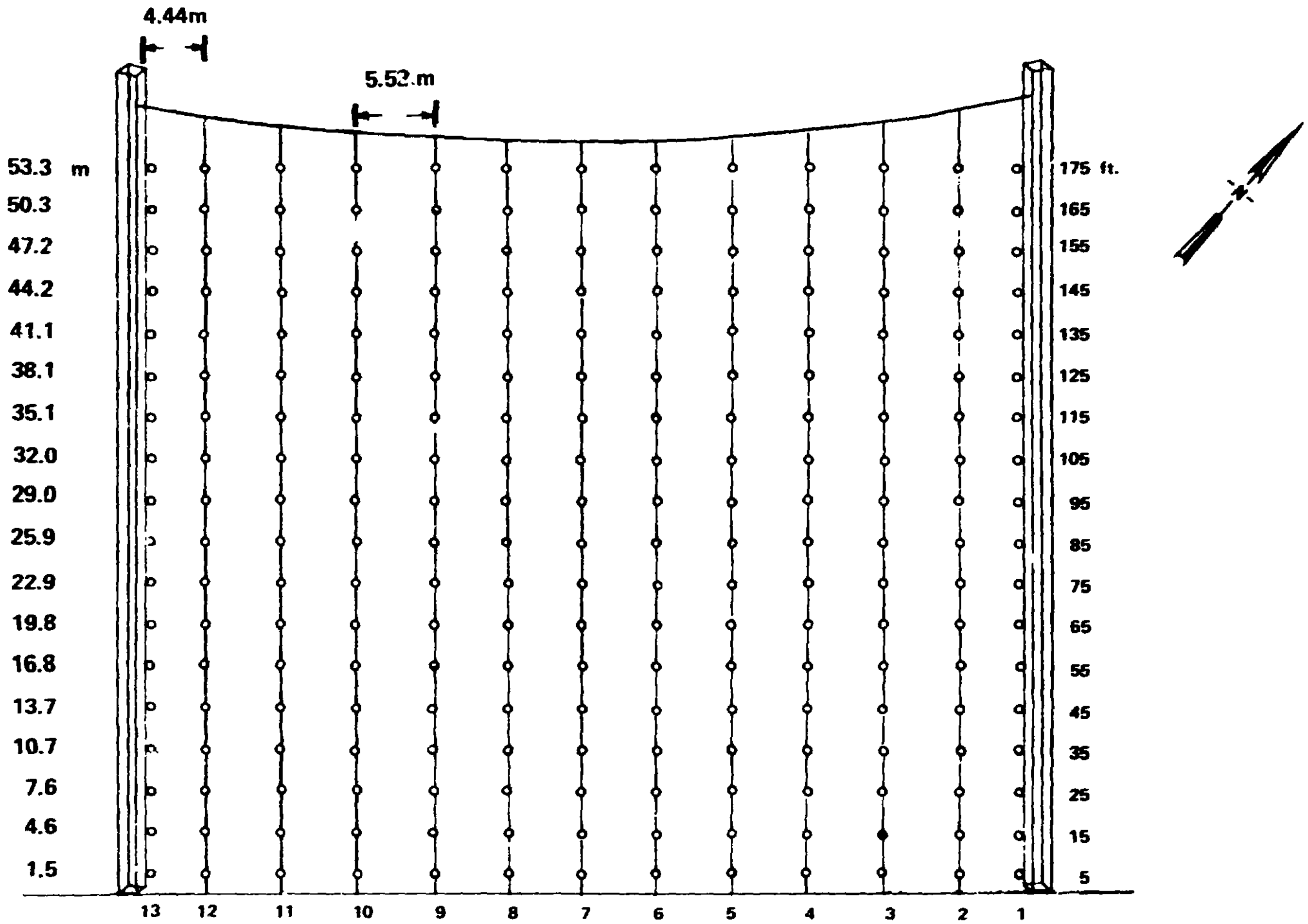

Figure B.5. Tower-Supported Vertical Array, Showing Stainless Steel Mesh Sampler Positions (Looking Upwind Towards Fire Pool).

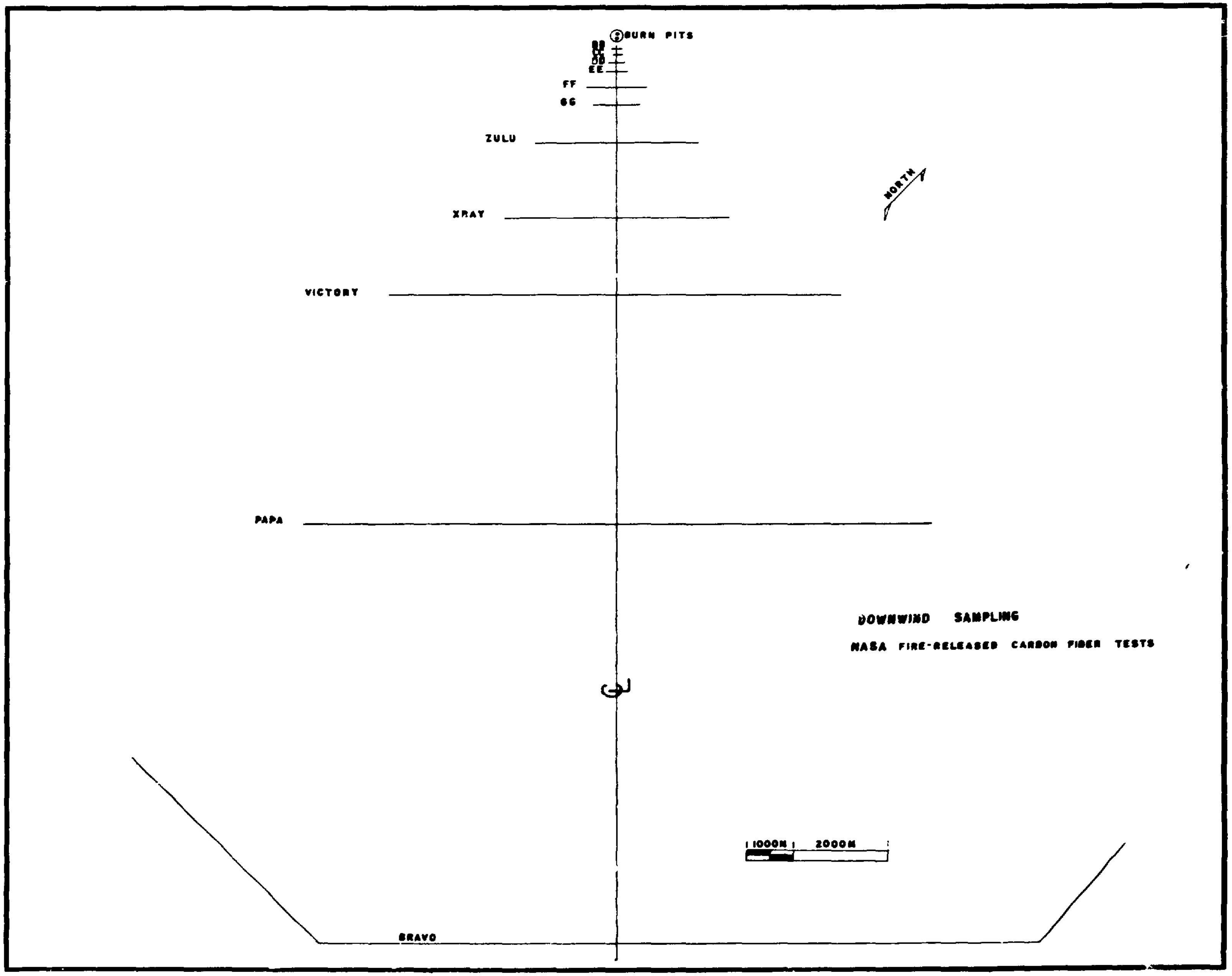

Figure B.6. Downwind Sample Rows [Distance from Center Burn Pit to Brovo is 191 m (11.8 mi)].

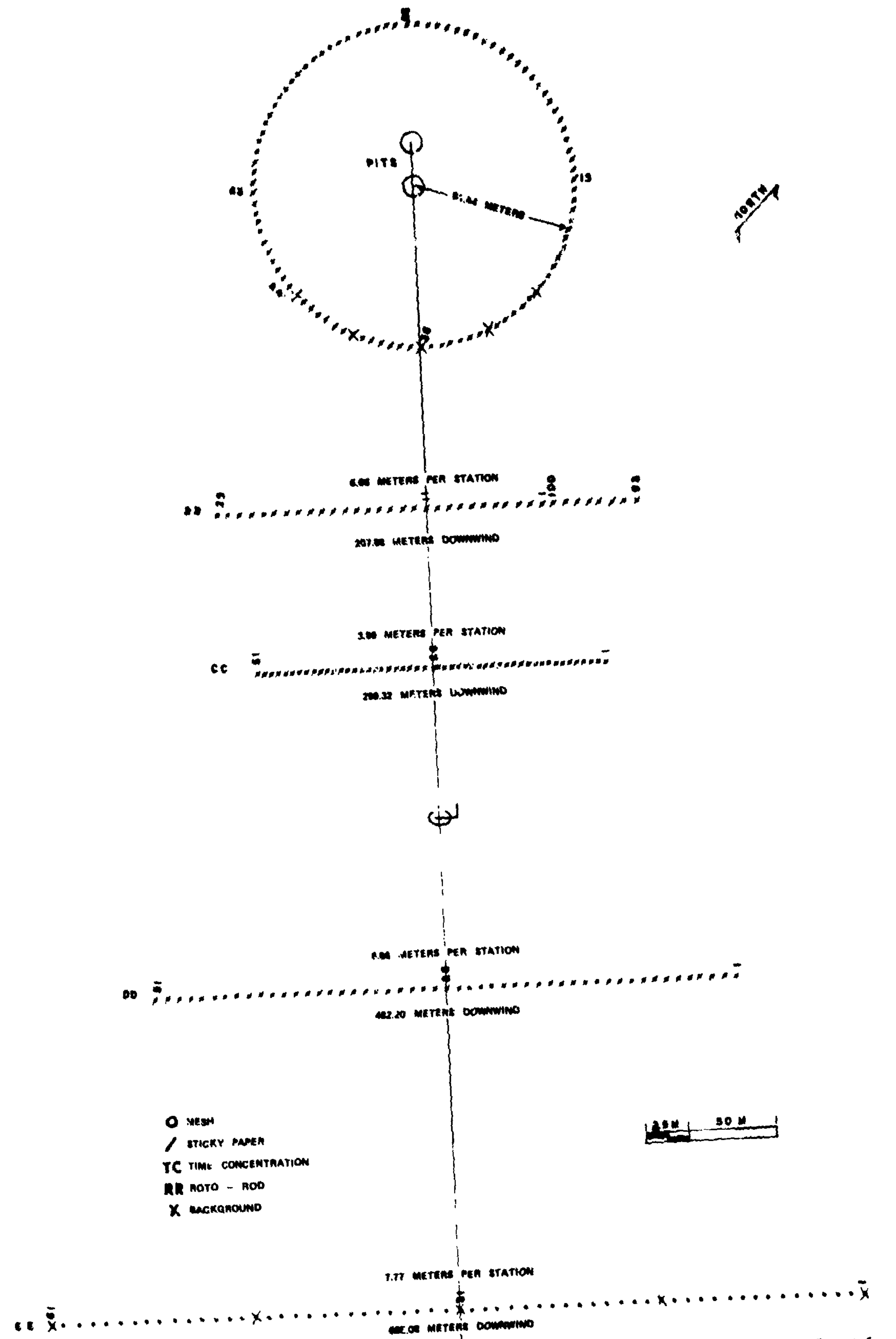

Figure B.7. Sampling Arc and Downwind Sampling Requirements and Station Positions (Arc AA through Row EE).

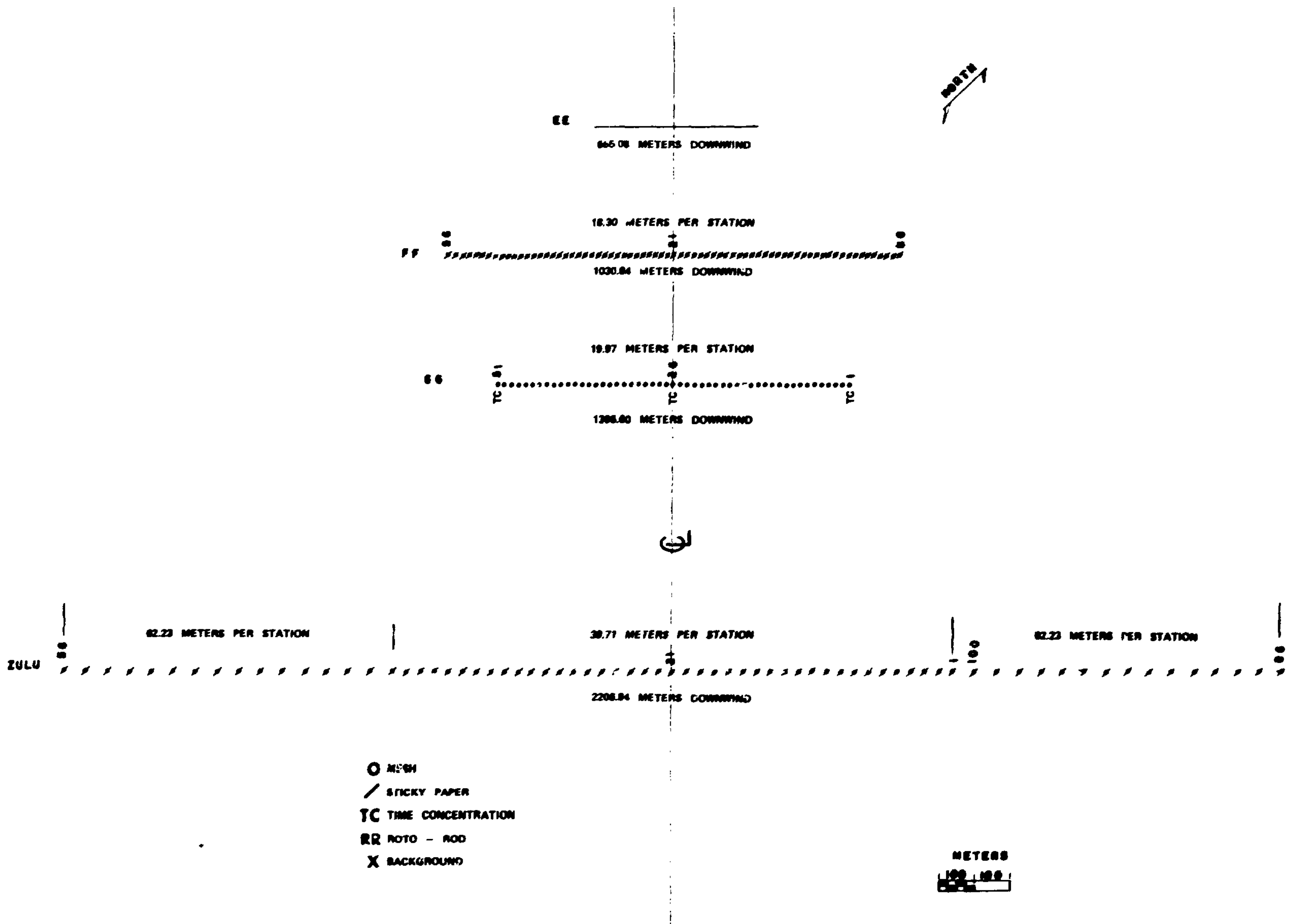

Figure B.8. Downwind Sampling Requirements and Station Positions (Row FF through Row Zulu).

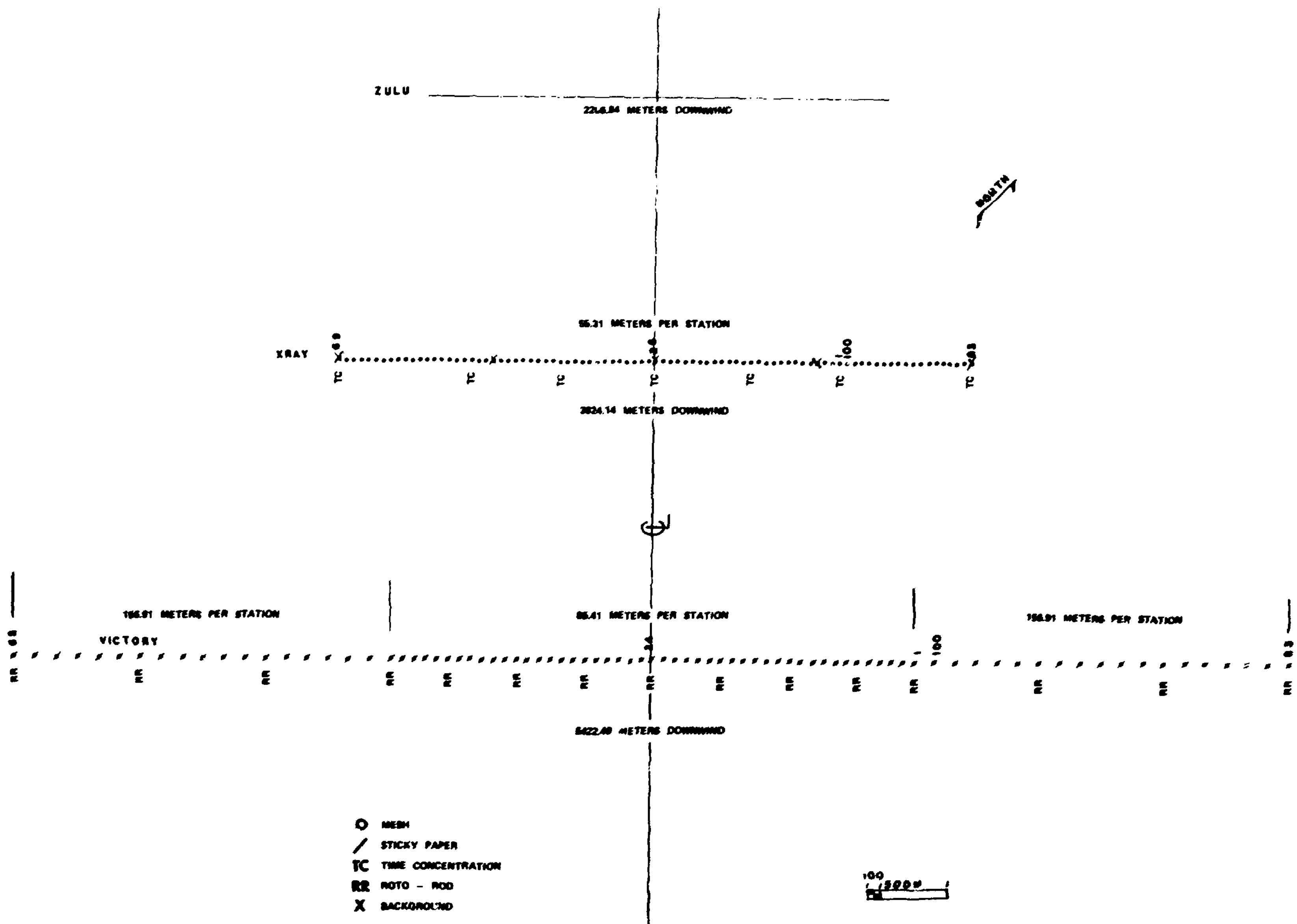

Figure B.9. Downwind Sampling Requirements and Station Positions (Row X-Ray through Row Victory).

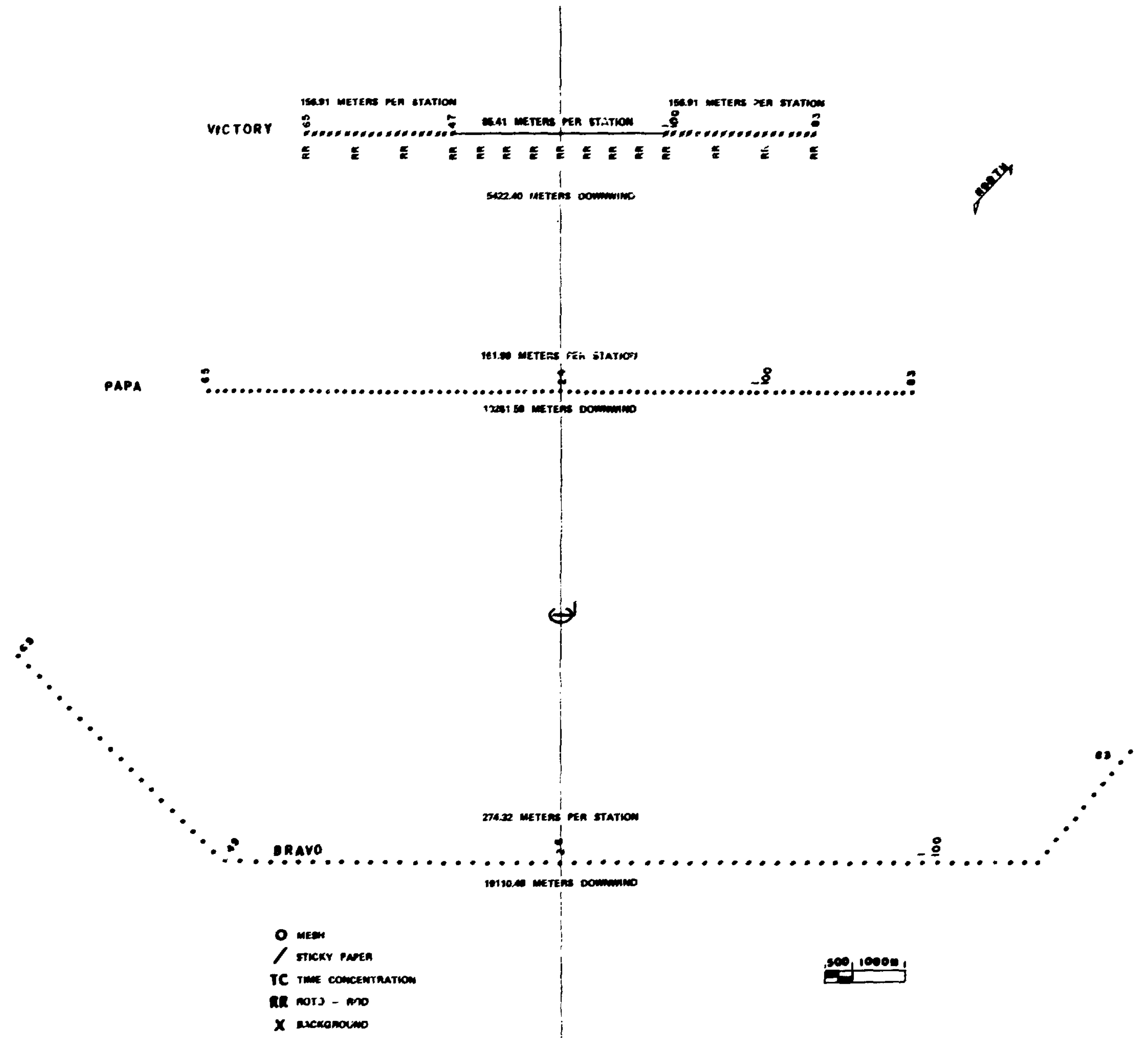

Figure B.10. Downwind Sampling Requirements and Station Positions (Row Victory through Row Bravo).

APPENDIX C. VERTICAL ARRAY CARBON FIBER DATA

Sampling efficiency of the stainless steel mesh samplers was determined during a methodology study conducted at DPG in December 1979 (Reference 10). The study was conducted on the carbon fiber vertical array. Samplers were placed on 11 vertical lines spaced 5.5 m apart and at heights of 1.5 and 4.6 m. Carbon fibers approximately 5 - 6 mm long and 8 μm in diameter were disseminated. Stainless steel mesh and nylon mesh samplers, assumed to have collection efficiencies of 100 percent, were "mixed" on the array. The stainless steel mesh samplers were the same as those used on the vertical array which was located approximately 60 m downwind of the pool fire. Analysis of the data indicated a 54 percent efficiency of the stainless steel mesh samplers compared to the 100 percent efficiency of the nylon mesh samplers.

During the pool fire tests soot and carbon fibers contained in the soot plume were collected by the grease-coated mesh of the samplers in the plume. It was expected that soot would reduce the efficiency of the samplers to collect single carbon fibers. Therefore, source strength estimates for input to source strength calculations would be lower than for samplers without soot. Because no data are available on change in sampler efficiency as a function of soot accumulation, DPG source strength measurements may be low for the stainless steel mesh sampler.

The percentage of slippage through the nylon mesh for carbon fibers 1 - 2 mm and 2 - 3 mm long was 15.6 and 8.8 percent, respectively (Reference 6). The slippage of carbon fibers through the stainless steel mesh was assumed to be the same as for the nylon mesh. Background counts of carbon fibers collected by the vertical array samplers from actual counts for the control samplers placed upwind of the pool fire are given in Table C.1. The widths of influence shown in Table C.2 were used to estimate total carbon fibers passing through the vertical sampling array. The equation on page C.2 was used to make the estimate and a description of carbon fiber passage through the array is given in paragraph 2.3.2.5.

Fibers collected on the stainless steel mesh sampler were reduced to fibers per square meter by the following equation:

$$\text{Fibers/m}^2 = \frac{\text{Total counts - background}}{\text{Efficiency x cos(wind angle) x Area of sampler x } (1-K_1-K_2)}$$

where;

Efficiency = 0.54 (54%)

Area of sampler = 0.00724 m^2

Wind angle = Angle of wind from line perpendicular to mesh screen (see Table C.1)

Background = Number of fibers considered as background (see Table C.1)

K_1 = 0.156 x P_1 (15.6% slippage in 1-2 mm category)

K_2 = 0.088 x P_2 (8.8% slippage in 2-3 mm category)

P_1 = Percent/100 of fibers in 1-2 mm category (see Table C.1)

P_2 = Percent/100 of fibers in 2-3 mm category (see Table C.1)

Table C.1. Constants Used to Convert Fiber Counts to Fibers/M^2.

Trial	Background Count	Wind Angle (degrees)	Percent of Fibers (1-2 mm)	Percent of Fibers (2-3 mm)
D-1	0	40	14.20	21.10
D-2	1	30	18.55	20.96
D-3	1	6	16.43	15.85

Table C.2. Vertical Sampling Line Widths of Influence.

Tower	Width of Influence (m)
1	4.44
2	5.52
3	5.52
4	5.52
5	5.52
6	5.52
7	5.52
8	5.52
9	5.52
10	5.52
11	5.52
12	5.52
13	4.44

Table C.3. Carbon Fibers Collected on Stainless Steel Mesh Samplers, Vertical Array, Pool Fire Trial D-1, 26 October 1979.

HEIGHT (M)	TOWER T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	PARTICLES PER M**2[a]	PARTICLES[b]	PERCENT
53.34	0	0	0	0	0	0	0	0	0	10790	12530	14271	2784	40375	670143	1.33
50.29	0	0	0	0	0	0	0	0	4176	7658	16012	23322	5220	56300	931543	1.84
47.24	0	0	0	0	0	0	0	0	5569	20085	23670	17404	20085	80413	1410795	2.81
44.20	0	0	0	0	0	0	0	3480	8006	19841	18797	16700	26003	93635	1407175	2.94
41.15	0	0	0	0	0	0	0	6961	6265	29240	13227	17752	26107	99552	1509019	3.14
38.10	0	0	0	0	0	0	0	6961	4524	9746	14620	18449	27040	82140	1290466	2.55
35.05	0	0	0	0	0	0	0	7658	14620	8701	15316	28543	29936	104774	1664275	3.29
32.00	0	0	0	0	0	0	0	7310	6961	25410	5220	24366	18449	87716	1415007	2.80
28.95	0	0	0	0	0	0	2436	4524	10094	29936	4524	19145	15664	86323	1400010	2.77
25.91	0	0	0	0	0	0	2088	13575	9398	11139	7658	49081	55696	140635	2317437	4.58
22.86	0	0	0	0	0	0	0	7310	24019	8353	3829	48305	47341	139237	2186819	4.32
19.81	0	0	0	0	0	0	0	4872	19493	26107	21581	64746	57000	196671	3111093	6.15
16.76	2784	0	0	0	0	0	3132	5569	24019	13575	14271	38639	30980	130105	2088377	4.13
13.72	0	0	0	0	0	0	0	10094	24019	38639	5220	71361	63702	213035	3374609	6.67
10.67	0	0	0	0	0	0	0	9398	22278	14960	18100	45601	5569	115914	1931917	3.82
7.62	0	0	0	0	0	0	0	8006	12879	20537	75006	50029	109303	285440	4442710	8.78
4.57	0	2088	0	0	0	0	0	14271	11487	41771	83544	167089	209210	529460	8219459	16.25
1.52	0	0	0	0	0	0	2784	13227	27151	65442	67532	244020	292755	712911	11030990	21.81
PARTICLES/M**2	2784	2088	0	0	0	0	10440	123216	234958	402730	421537	967711	1045340	3210012		
PARTICLES	37676	35131	0	0	0	0	175654	2073107	3953162	6776053	7092347	16281706	14146714		50571540	
PERCENT	.07	.07	.00	.00	.00	.00	.35	4.10	7.82	13.44	14.02	32.20	27.97			100.00

[a] Total particles per M^2 for all samplers at a given height.
[b] Total particles per M^2 for entire area sampled at a given height.

NOTE: M ** 2 = M^2

Table C.4. Carbon Fibers Collected on Stainless Steel Mesh Samplers, Vertical Array, Pool Fire Trial D-2, 31 October 1979.

HEIGHT (M)	TOWER T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	PARTICLES PER M**2 [a]	PARTICLES[b]	PERCENT
53.34	6819	4029	25732	41544	39684	9300	0	0	0	0	0	0	0	127108	2116140	2.06
50.29	46614	7130	41544	36583	27282	6510	0	0	0	0	0	0	0	159663	2552630	2.49
47.24	15500	32553	39374	55186	31623	10541	2479	0	0	0	0	0	0	107256	3099551	3.02
44.20	67897	12090	17361	46505	35653	6200	5580	0	0	0	0	0	0	191286	2994875	2.92
41.15	16431	11471	43404	38444	45884	12710	6819	0	0	0	0	0	0	175163	2893024	2.82
38.10	14261	12090	44024	57046	48985	12401	6200	0	0	0	0	0	0	195007	3234042	3.15
35.05	74717	10850	37203	38444	28522	15191	2479	0	0	0	0	0	0	207406	3243642	3.16
32.00	74717	13331	17051	63556	66347	9920	2790	0	0	0	0	0	0	247712	3921790	3.62
28.95	43094	48674	32863	62316	58906	15500	2479	0	0	0	0	0	0	263032	4297111	4.19
25.91	52085	43494	48365	42474	42784	4959	0	0	0	0	0	0	0	234071	3766700	3.67
22.86	21391	33173	60766	67587	46814	3099	0	0	0	0	0	0	0	232830	3846941	3.75
19.81	146336	61386	54486	68827	58285	0	0	0	0	0	0	0	0	399320	6236837	6.08
16.76	171449	35033	58906	98280	12401	0	0	0	0	0	0	0	0	376069	5762973	5.62
13.72	145406	44644	112232	90840	8680	0	0	0	0	0	0	0	0	401802	6281659	6.12
10.67	170519	70680	93319	81848	16431	0	1239	0	1549	0	0	0	0	435593	6767522	6.60
7.62	198732	141686	184780	44954	9300	3409	1549	2479	619	930	0	0	0	500430	9246256	9.01
4.57	226946	389095	124633	47435	53945	6510	4650	3720	5889	1549	0	0	0	864372	13795956	13.44
1.52	255159	447071	178579	90529	80608	33483	22942	15811	23562	3099	1860	0	0	1152703	18554252	18.08
LES/M**2	1742073	1418398	1224622	1072390	712134	149733	59206	22010	31619	5578	1860	0	0	6439631		
LES	23575684	23864496	20604220	18043060	11981634	2519253	996138	370317	531909	93850	31294	0	0		102611901	
NT	22.98	23.26	20.08	17.52	11.68	2.46	.97	.36	.52	.09	.03	.00	.00			100.00

al particles per M^2 for all samplers at a given height.
al particles per M^2 for entire area sampled at a given height.

: M ** 2 = M^2

Table C.5. Carbon Fibers Collected on Stainless Steel Mesh Samplers, Vertical Array, Pool Fire Trial D-3, 9 November 1979.

HEIGHT (M)	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	PARTICLES PER M**2[a]	PARTICLES[b]	PERCENT
53.34	18207	6961	7496	4015	12316	26239	14726	19814	12584	20885	10174	4284	0	157701	2593370	2.55
50.29	7764	19546	7496	13387	18475	17671	16600	63458	8299	15797	5890	5890	0	200273	3344029	3.29
47.24	15261	27311	14993	19546	24633	20616	17671	64797	27311	55425	8299	4015	4284	304162	5053179	4.98
44.20	11513	24365	11781	27311	34540	24633	37754	34805	52748	57835	3212	7229	20349	347275	5730006	5.65
41.15	23562	15261	27578	31327	48196	42038	29184	36682	25972	44983	20885	6158	5354	357180	5914357	5.82
38.10	0	20885	25437	15797	26775	41234	34540	52748	55961	33470	4551	4284	7229	322911	5409171	5.33
35.05	38021	14458	27043	24365	23830	18207	41502	22759	27847	28917	4284	3212	4819	279264	4557508	4.49
32.00	10709	23830	29988	30523	18475	20081	20616	51409	20081	27311	13119	8568	3747	270457	4637444	4.57
28.95	3480	27578	23026	48732	20616	42573	38021	71491	42573	25169	17403	12040	2945	375655	6299236	6.20
25.91	28649	22759	20349	54890	47393	46589	62119	23830	37485	21688	6158	16332	11245	399406	6590014	6.49
22.86	11245	7229	22223	65860	46857	56764	57568	39360	20616	9907	4551	13654	15529	371371	6160171	6.07
19.81	16060	17136	42573	78988	61584	39895	219831	34805	21152	21955	21955	10442	16868	603252	10030642	9.88
16.76	20349	3480	27311	74704	51409	27311	97732	27847	42573	20616	34805	15529	19814	462600	7652367	7.53
13.72	0	1606	32933	42033	38021	67475	51945	62119	27578	32666	21152	39895	22491	439919	7327506	7.21
10.67	0	0	5354	27043	16868	23562	42038	55425	31862	21955	35344	27847	23030	311120	5156274	5.08
7.62	0	0	0	5622	15797	29184	28382	20616	42038	51409	53284	30523	13119	289974	4835610	4.76
4.57	1873	0	0	5086	11513	29988	15797	35879	43912	40699	34805	20349	2409	241510	4049303	3.99
1.52	1606	2676	4284	9638	47393	54086	21688	46054	72830	39360	29184	21955	23294	374040	6211379	6.12
PARTICLES/M**2	209107	235001	329365	578880	564691	628146	847714	762298	613422	570047	327455	252214	197326	6116246		
PARTICLES	2837071	3955233	5549973	9739638	9500910	10568540	14262760	12825642	10320806	9591026	5509420	4243491	2670437		101567742	
PERCENT	2.79	3.89	5.46	9.59	9.35	10.41	14.04	12.63	10.16	9.44	5.42	4.18	2.63			100.00

[a]Total particles per M^2 for all samplers at a given height.
[b]Total particles per M^2 for entire area sampled at a given height.

NOTE: M ** 2 - M^2

Table C.6. Source Strength of Carbon Fiber Clumps From Vertical Array, Trial D-1, Carbon Fiber Pool Fire Test.

Size Category (No. of Fibers/Clump)	Number of Clumps	Percent of Total Number of Clumps
2 - 5	4.2×10^6	36.9
6 - 10	3.6×10^6	31.8
11 - 20	0.1×10^6	0.5
21 - 50	2.8×10^6	24.8
51 - 100	0.4×10^6	3.2
101 - 300	0.1×10^6	1.5
301 - 500	0.1×10^6	0.5
> 500	0.1×10^6	0.9
Total	11.4×10^6	

Table C.7. Source Strength of Carbon Fiber Clumps From Vertical Array, Trial D-2, Carbon Fiber Pool Fire Test.

Size Category (No. of Fibers/Clump)	Number of Clumps	Percent of Total Number of Clumps
2 - 5	18.6×10^6	42.0
6 - 10	15.6×10^6	35.2
11 - 20	2.3×10^6	5.3
21 - 50	5.4×10^6	12.2
51 - 100	1.4×10^6	3.1
101 - 300	0.3×10^6	0.7
301 - 500	0.4×10^6	1.0
> 500	0.2×10^6	0.5
Total	44.2×10^6	

Table C.8. Source Strength of Carbon Fiber Clumps From Vertical Array, Trial D-3, Carbon Fiber Pool Fire Test.

Size Category (No. of Fibers/Clump)	Number of Clumps	Percent of Total Number of Clumps
2 - 5	1.6×10^6	11.1
6 - 10	5.7×10^6	40.0
11 - 20	2.7×10^6	19.1
21 - 50	1.8×10^6	12.3
51 - 100	0.6×10^6	4.1
101 - 300	1.0×10^6	7.0
301 - 500	0.7×10^6	5.0
> 500	0.2×10^6	1.4
Total	14.3×10^6	

APPENDIX D. DOWNWIND CARBON FIBER DATA

Efficiency of nylon mesh samplers (cardboard and metal can) was considered to be 100 percent (Reference 11). The total collecting surfaces of the cardboard nylon mesh and metal can nylon mesh samplers were 56.75 cm^2 and 72.4 cm^2, respectively. The wind angle for Trial D-1, Rows BB through GG was 40° and 20° for Rows Z, X, V, P, and B. The wind angle for Arc AA was 0° for all trials. The wind angles for all rows on Trials D-2 and D-3 was 30° and 6°, respectively. The total collecting surface of the sticky paper sampler was 104.78 cm^2.

Background carbon fiber counts averaged <1 for all trials. Only data for grid positions with significant carbon fibers (more than one) per sampler were converted to carbon fibers/m^2 (see equation in Appendix C) and appear in this Appendix. Grid positions (arc or row and number) are shown in Figures B.7 through B.10.

Data presented in Tables D.1 through D.6 are for carbon fibers collected on mesh samplers. Tables D.7 through D.10 are carbon fibers collected in sticky paper samplers.

Table D.1. Carbon Fibers Collected on Nylon Mesh Cardboard Samplers, Pool Fire Trial D-1, 26 October 1979.

Position No.	Fibers/M^2	Position No.	Fibers/M^2
ARC AA			
38	753	49	55744
39	1130	50	67232
40	2637	51	61770
41	8851	52	54049
42	9040	53	38230
43	12241	54	25800
44	16008	55	8663
45	9605	56	7721
46	16008	57	7533
47	24105	58	3010
48	35217	59	1507
ROW BB			
12	1474	21	12531
13	737	22	14251
14	2211	23	15971
15	2211	24	23587
16	1720	25	24816
17	1229	26	25061
18	2211	27	21622
19	4668	28	22604
20	7862	29	35381
ROW CC			
5	2703	31	737
6	1229	32	491
7	737	34	983
8	1229	35	1474
9	1229	36	1720
10	491	37	983
11	737	38	983
12	737	39	983
13	983	40	1474
14	737	41	1720
15	491	42	1474
16	491	43	1720
17	3194	44	1229
19	983	45	1474
20	983	46	1474
22	737	47	1720
23	983	48	3931
24	2211	49	6634
25	2211	50	7617
26	1229	51	5160
28	491		

Table D.1. Carbon Fibers Collected on Nylon Mesh Cardboard Samplers, Pool Fire Trial D-1, 26 October 1979 (cont'd).

Position No.	Fibers/M^2	Position No.	Fibers/M^2
	ROW DD		
5	491	43	2457
28	491	44	983
29	737	45	5160
30	491	46	1229
32	1229	47	1474
33	737	49	1474
34	983	50	983
38	983	51	1474
41	491		
	ROW FF[a]		
42	737	52	1474
46	1229	53	1474
47	2211	54	2211
48	1229	55	1229
49	491	56	5405
50	491		
	ROW GG[a]		
30	3194	43	6143
31	1229	44	1720
32	3194	45	1474
33	1474	49	2703
37	2211	50	1720
38	2948	51	2457
39	1474		

Table D.1. Carbon Fibers Collected on Nylon Mesh Cardboard Samplers, Pool Fire Trial D-1, 26 October 1979 (cont'd).

ROW Zulu			
Position No.	Fibers/M^2	Position No.	Fibers/M^2
19	802	42	401
20	601	52	1002
21	1002	54	401
32	401	55	601
38	401	90	401
ROW X-Ray			
55	401		
ROW Victory			
22	601	35*	802
29	401	38	601
31	802	39	802
32	1603	40	1403
33	601	100	401
35*	1605		
ROW Papa			
1	601	52	601
4	802	53	802
6	802	54	601
15	601	55	1403
16	601	56	601
18	401	57	601
19	401	58	1403
25	401	59	601
26	401	61	1202
27	601	62	401
30	601	64	1002
34	802	65	401
43	1002	83	401
45	601	86	601
46	802	87	401
47	601	89	401
48	802	97	401
50	802	98	401
51	601	99	401

Table D.1. Carbon Fibers Collected on Nylon Mesh Cardboard Samplers, Pool Fire Trial D-1, 26 October 1979 (cont'd).

ROW Bravo			
Position No.	Fibers/M^2	Position No.	Fibers/M^2
8	401	60	601
49	401	61	401
53	601	62	601
54	401	63	401
55	1603	65	401
56	601	66	401
58	601	68	601

[a]Samplers on rows FF and GG contained both cardboard and metal can samplers covered with nylon mesh. These data are for cardboard samplers with an area of 56.75 cm^2. See Table D.2 for metal can sampler data.
*Misidentified samplers

Table D.2. Carbon Fibers Collected on Nylon Mesh Can Samplers, Pool Fire Trial D-1, 26 October 1979.

ROW FF[a]			
Position No.	Fibers/M^2	Position No.	Fibers/M^2
86	385	95	385
89	385	103	578

ROW GG[a]			
1	2119	20	578
2	4046	21	1156
3	3468	22	1156
4	963	23	1927
5	771	24	1541
6	3854	25	1349
7	1156	26	7707
8	1156	27	1927
9	963	28	1349
10	1927	29	4624
11	578	34	2697
12	3468	35	2890
13	1349	36	2505
14	385	40	1927
15	385	41	3661
16	578	42	2312
17	963	46	963
18	1156	47	2890
19	578	48	1927

[a]Samplers on rows FF and GG contained both cardboard and metal can samplers covered with nylon mesh. These data are for metal cans with an area of 72.40 cm^2. See Table D.1 for cardboard sampler data.

Table D.3. Carbon Fibers Collected on Nylon Mesh Cardboard Samplers, Pool Fire Trial D-2, 31 October 1979.

Position No.	Fibers/M²	Position No.	Fibers/M²
ARC AA			
13	386	37	7144
21	386	38	3282
25	5600	39	2896
26	23170	40	2317
27	65264	41	2124
28	90365	42	772
29	72022	43	579
30	45182	44	579
31	49044	45	772
32	29349	48	579
34	23557	73	579
35	18729	77	386
36	11199	86	386
ROW BB			
1	3122	93	4013
2	1115	94	8250
3	2007	95	11148
4	1784	96	9142
5	1115	97	10925
6	669	98	10702
7	446	99	5797
9	446	100	5351
ROW CC			
1	3122	10	1338
2	1115	11	1115
3	892	13	892
4	446	14	669
5	2899	18	446
8	669	19	892
9	669	26	446
ROW DD			
1	1784	8	892
2	892	10	1115
3	669	12	1115
4	1561	13	446
5	446	14	446
6	669	18	446
7	669		

Table D.3. Carbon Fibers Collected on Nylon Mesh Cardboard Samplers, Pool Fire Trial D-2, 31 October 1979 (cont'd).

Position No.	Fibers/M²	Position No.	Fibers/M²
	ROW EE		
1	669		
	ROW FF		
2	446	95	892
3	669	97	669
92	669	98	1784
93	6912	100	669
94	446		
	ROW GG		
1	669	13	446
2	446	31	669
3	669	42	446
5	446	45	446
10	446	51	446
	ROW Zulu		
1	1115	8	446
2	446	14	669
3	446	20	446
4	446	99	1115
5	446	100	446
	Row X-Ray		
1	446	15	446
2	892	16	2230
4	446	17	1338
5	892	18	1338
6	446	19	446
7	892	20	892
8	669	22	446
9	669	24	1784
10	1561	25	892
11	1115	26	669
14	446	35	446

Table D.3. Carbon Fibers Collected on Nylon Mesh Cardboard Samplers, Pool Fire Trial D-2, 31 October 1979 (cont'd).

Position No.	Fibers/M^2	Position No.	Fibers/M^2
ROW Victory			
1	446	9	2453
3	669	11	1115
4	1338	26	669
5	892	34	446
6	2007	95	446
7	669		
ROW Papa			
5	669	13	669
6	446	14	446
8	446	15	669
9	669	16	669
11	2899	17	446
ROW Bravo			
7	446	14	446
8	446	20	892
10	446	36	446
11	446	45	446
12	446	47	669

Table D.4. Carbon Fibers Collected on Nylon Mesh Cardboard Samplers, Pool Fire Trial D-3, 9 November 1979.

ARC AA			
Position No.	Fibers/M^2	Position No.	Fibers/M^2
7	572	48	29765
8	382	49	3053
27	572	50	6487
28	1526	51	11830
30	1908	52	2671
31	9159	53	11830
32	8205	54	8205
33	7632	55	7251
34	13738	56	6106
35	16027	57	2290
36	62583	58	2862
37	43503	59	1145
38	57241	60	572
39	33581	61	1145
40	43503	83	763
41	32055	85	763
42	42740	86	572
43	37397	87	382
44	45793	88	572
45	39687	89	572
46	28239	95	382
47	46556	97	382
ROW BB			
3	1535	19	7675
4	2494	20	7291
5	5948	21	8442
6	7866	22	9210
7	14965	23	7483
8	12663	24	9401
9	12855	25	7866
10	12087	26	8250
11	12663	27	4221
12	8058	28	6523
13	7866	29	6140
14	12279	93	959
15	11128	94	959
16	9977	96	576
17	6907	97	767
18	8250	98	1919

Table D.4. Carbon Fibers Collected on Nylon Mesh Cardboard Samplers, Pool Fire Trial D-3, 9 November 1979 (cont'd).

ROW CC			
Position No.	Fibers/M^2	Position No.	Fibers/M^2
1	576	30	7291
3	384	31	6523
4	384	32	5372
5	384	33	36071
8	384	34	11512
9	1343	35	10744
12	384	36	6332
15	1343	37	8058
16	1919	38	7291
17	2878	39	5948
18	6715	40	7291
19	11320	41	6140
20	9210	42	3454
21	5180	43	3837
22	7675	44	5180
23	7675	45	3645
24	7866	46	4413
25	6715	47	5180
26	7866	48	5564
27	6907	49	4988
28	6332	50	3645
29	8442	51	4029

ROW DD			
1	576	31	1151
3	576	32	1343
5	384	33	959
8	576	34	1151
9	384	35	4988
10	576	36	2302
16	384	37	959
17	767	38	2302
18	1151	39	1919
20	1727	40	959
21	2111	41	1343
22	1343	42	2494
23	1535	43	2686
24	1727	45	1919
25	1919	46	1919
26	1343	47	2494
27	767	48*	1727
28	1151	48*	2878
29	384	49	3262
30	2302	50	3454

Table D.4. Carbon Fibers Collected on Nylon Mesh Cardboard Samplers, Pool Fire Trial D-3, 9 November 1979 (cont'd).

ROW EE			
Position No.	Fibers/M²	Position No.	Fibers/M²
5	767	39	2302
7	576	40	959
8	384	41	576
11	384	42	1343
18	384	43	1151
20	384	44	1343
21	384	45	1343
22	576	46	959
23	1535	47	1535
24	2111	48	1151
25	959	49	1151
26	1727	50	384
27	2302	51	767
28	2686	52	384
29	2111	53	767
30	1343	54	1727
32	1151	55	1919
33	959	56	1343
34	1535	57	1535
35	576	58	1919
36	1151	59	1727
37	767	60	2494
38	1151	61	3454

Table D.4. Carbon Fibers Collected on Mesh Nylon Cardboard Samplers, Pool Fire Trial D-3, 9 November 1979 (cont'd).

ROW FF

Position No.	Fibers/M²	Position No.	Fibers/M²
2	2302	29	576
3	384	31	576
4	1151	34	384
5	576	35	576
8	384	36	767
9	384	37	1535
10	384	38	767
14	767	39	959
16	384	40	1151
17	767	41	1919
18	1343	42	1343
19	1727	43	576
20	959	44	2111
21	959	46	384
22	1151	47	1151
23	384	48	2494
24	1343	49	384
25	959	50	384
26	1727	100	384
27	767		
28	767		

ROW GG

Position No.	Fibers/M²	Position No.	Fibers/M²
6	384	28	576
9	576	30	767
11	384	31	1151
19	384	32	576
21	576	33	1343
22	576	37	576
23	576	49	384
24	767	51	959
26	576	61	384
27	767		

Table D.4. Carbon Fibers Collected on Nylon Mesh Cardboard Samplers, Pool Fire Trial D-3, 9 November 1979 (cont'd).

ROW Zulu

Position No.	Fibers/M^2	Position No.	Fibers/M^2
10	384	28	767
18	384	29	384
19	1919	30	384
20	1343	32	767
21	2686	38	576
23*	384	42	576
23*	576	44	384
24	2494	45	959
25	576	48	576
26	959	49	767
27	767	50	1151

ROW X-ray

Position No.	Fibers/M^2	Position No.	Fibers/M^2
6	767	30	384
27	576	31	959
28	767	33	767
29	767	64	384

ROW Victory

Position No.	Fibers/M^2	Position No.	Fibers/M^2
30	384	86	384
31	959		

ROW Papa

Position No.	Fibers/M^2	Position No.	Fibers/M^2
10	384	60	384
20	384	94	384
59	384		

ROW Bravo

Position No.	Fibers/M^2	Position No.	Fibers/M^2
26	384	56	384
39	576	83	384
41	384		

* Misidentified samplers

Table D.5. Carbon Fibers Collected on Nylon Mesh Cardboard Samplers, Pool Fire Trial S-1, 15 November 1979.

ARC AA			
Position No.	Fibers/M^2	Position No.	Fibers/M^2
27	385	77	385
29	962	78	6156
67	577	79	770
70	577	80	770
71	770	81	962
73	385	87	385
75	962	94	385

Table D.6. Carbon Fibers Collected on Nylon Mesh Cardboard Samplers, Pool Fire Trial S-2, 28 November 1979.

ARC AA			
Position No.	Fibers/M^2	Position No.	Fibers/M^2
7	390	24	4875
8	585	25	2730
11	780	26	3315
13	780	27	585
14	585	29	1170
15	1755	30	1560
16	2925	32	975
17	2145	34	390
18	2145	36	390
19	10921	37	585
20	10531	44	390
21	7020	64	585
22	8385	67	390
23	4875		

Table D.7. Carbon Fibers Collected on Sticky Paper Samplers, Pool Fire Trial D-1, 26 October 1979.

Position No.	Fibers/M²	Position No.	Fibers/M²
	ROW BB		
15	95	56	573
20	95	57	668
52	191	58	286
53	573	59	954
55	477	94	477
	ROW CC		
30	95	49	191
46	191	51	286
	ROW DD		
25	95	32	477
	ROW EE		
1	95	28	95
19	95	35	95
27	95	51	95
	ROW FF		
15	95	56	191
22	95	88	95
23	95	89	95
38	95	96	95
39	477	102	95
44	95	109	477
	ROW Victory		
25	95	62	95
45	95	64	95
49	95	84	95
53	95	86	95
61	95	89	95

NOTE: Sticky paper samplers were not used on sampling Arc AA during this trial.

Table D.8. Carbon Fibers Collected on Sticky Paper Samplers, Pool Fire Trial D-2, 31 October 1979.

Position No.	Fibers/M^2	Position No.	Fibers/M^2
ARC AA			
26	382	38	286
27	859	39	95
28	2004	40	95
29	2386	41	95
30	1432	42	95
31	2004	45	286
32	668	47	382
34	668	48	191
35	764	49	95
36	286		
ROW CC			
2	95	8	95
4	191	13	95
6	191	33	95
7	95		
ROW DD			
10	95	16	95
ROW FF			
11	95	41	95
21	95	42	95
26	95	46	95
ROW Victory			
8	95	32	95
19	286	48	95
26	191	82	95
28	95	83	95
29	191	86	95
30	191		

Table D.9. Carbon Fibers Collected on Sticky Paper Samplers, Pool Fire Trial D-3, 9 November 1979.

Position No.	Fibers/M^2	Position No.	Fibers/M^2
ARC AA			
16	95	50	95
27	95	51	286
28	1241	52	191
29	286	53	382
32	573	54	477
33	668	55	477
34	382	56	286
35	1050	57	95
36	1241	58	95
37	1432	59	95
38	859	62	95
39	191	63	95
40	859	77	191
41	859	78	95
42	859	80	95
43	3340	82	95
44	573	83	286
45	573	84	95
46	668	86	95
47	477	97	191
48	573	99	95
49	573		
ROW BB			
4	95	17	477
5	191	18	286
6	95	19	191
7	764	20	573
8	2195	21	191
9	95	52	2004
10	191	53	191
11	95	56	191
12	191	57	286
14	668	59	286
15	286	93	191
16	191	95	95

Table D.9. Carbon Fibers Collected on Sticky Paper Samplers, Pool Fire Trial D-3, 9 November 1979 (cont'd).

Position No.	Fibers/M^2	Position No.	Fibers/M^2
ROW CC			
5	95	26	95
7	191	27	191
9	95	34	191
14	95	35	95
16	95	39	95
19	2386	40	95
20	191	42	95
22	191	43	191
23	286	45	95
24	95	47	95
25	95	48	95
ROW DD			
16	191	31	191
17	95	35	191
22	95	45	191
25	95	48	95
28	191	50	95
ROW FF			
22	95	97	95
39	191	100	95
93	286		
ROW Zulu			
1	382	12	1622
2	1145	13	382
3	477	14	382
4	382	24	95
5	477	29	95
6	859	50	95
7	1622	56	95
8	1718	95	95
9	382	96	95
10	573	99	286
11	382		

Table D.9. Carbon Fibers Collected on Sticky Paper Samplers, Pool Fire Trial D-3, 9 November 1979 (cont'd).

ROW Victory			
Position No.	Fibers/M^2	Position No.	Fibers/M^2
22	95	52	95
29	95	53	95
35	191	54	95
36	95	62	95
45	95		

Table D.10. Carbon Fibers Collected on Sticky Paper Samplers, Pool Fire Trial S-1, 15 November 1979.

ROW AA			
Position No.	Fibers/M^2	Position No.	Fibers/M^2
3	95	56	286
6	95	61	95
8	95	75	95
15	191	78	191
15	191	82	95
40	191	89	191
41	95	94	191

Table D.11. Carbon Fibers Collected on Sticky Paper Samplers, Pool Fire Trial S-2, 28 November 1979.

ROW AA			
Position No.	Fibers/M^2	Position No.	Fibers/M^2
1	95	36	95
17	95	38	191
19	95	40	95
20	382	41	95
21	477	42	191
22	95	44	286
23	573	45	95
24	95	50	191
26	191	59	95
28	382	75	382
29	764	76	95
30	191	77	95
34	382	81	95
35	191		

APPENDIX E. OVERHEAD CANOPY SAMPLER ARRAY DATA

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Figure E.1. Photograph of Overhead Canopy Sampler Array.

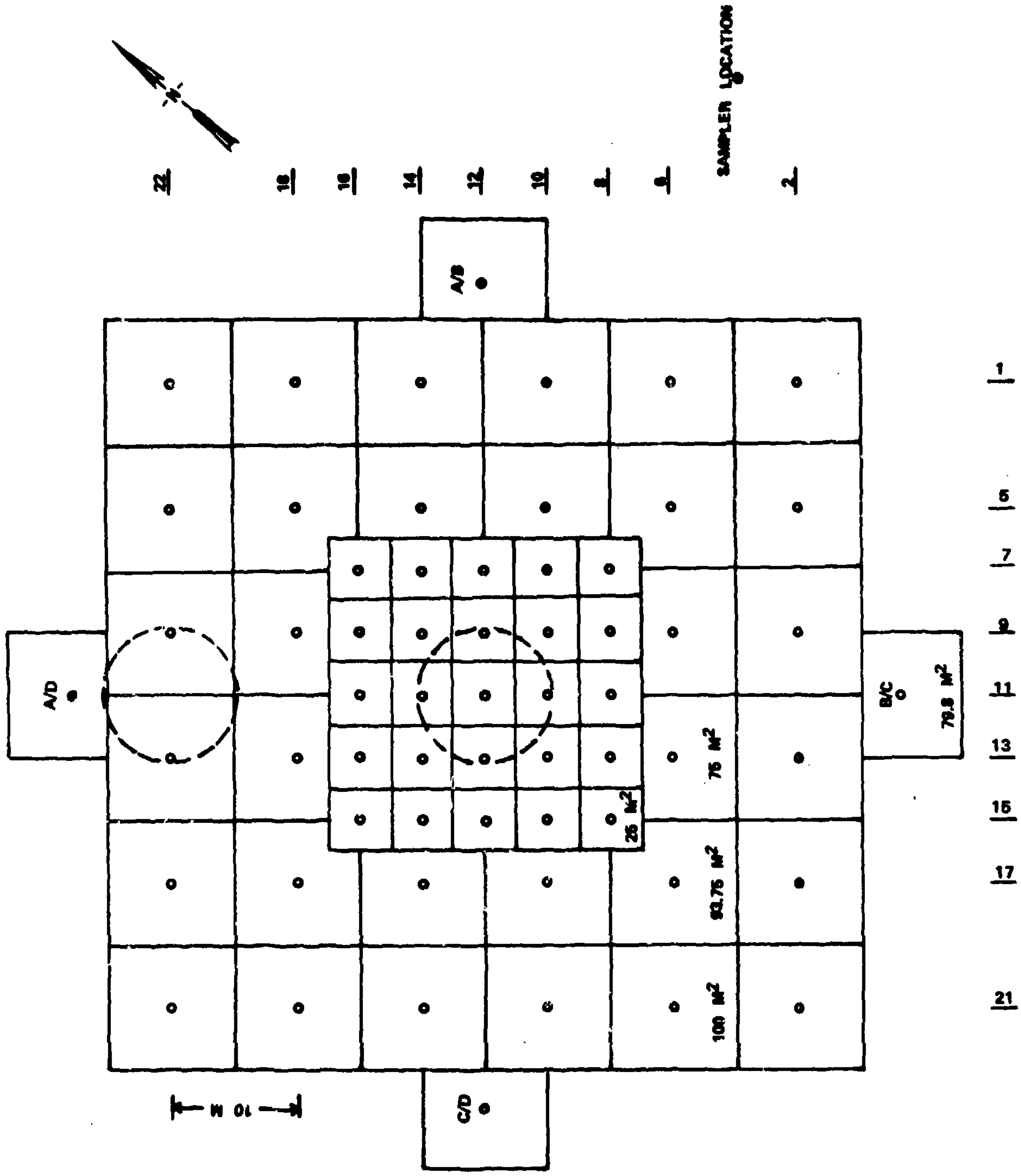

Figure E.2. Diagram of Overhead Canopy Sampler Array Showing "Peterson" Sampler Locations and Associated Area.

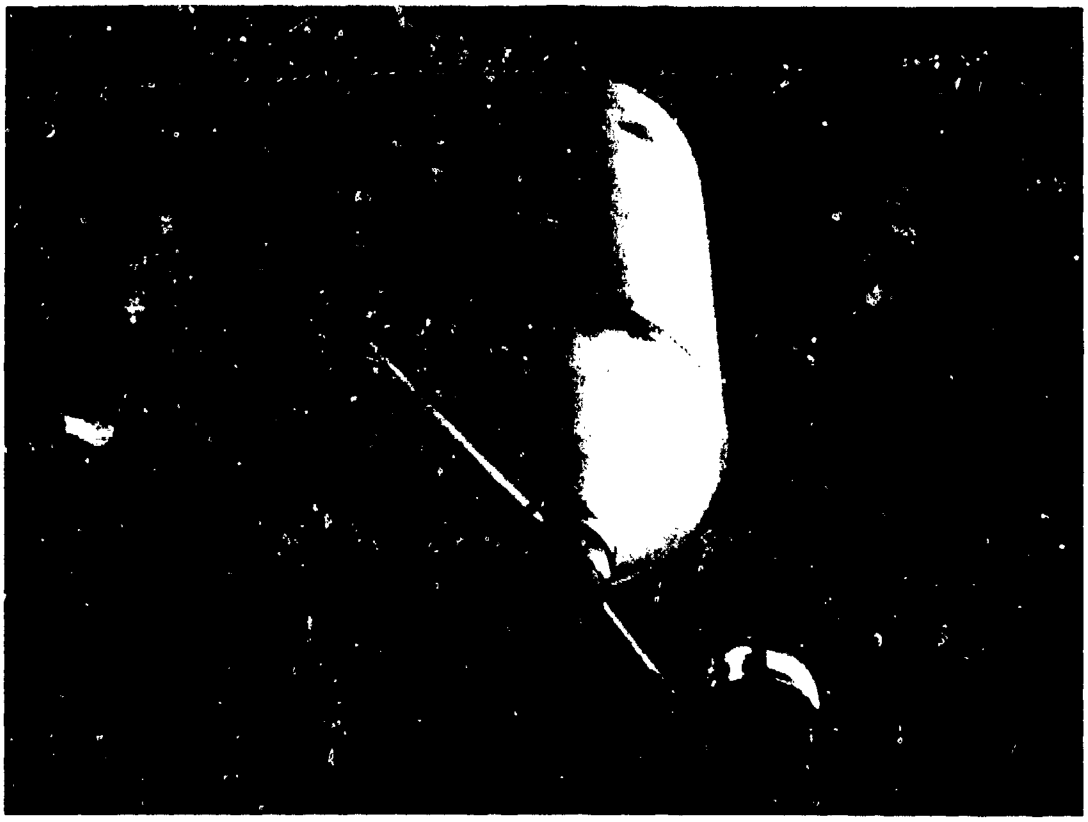

Figure E.3. Photograph of "Peterson" Sampler and Attached Stainless Steel Mesh Samplers.

Table E.1. Single Fiber Counts for Each Overhead Canopy Array Sampler Assayed, by Trial.

Sampler	Trial D1	D2	D3	S1 PET[a]	S1 SS[b]	S2 PET	S2 SS
2 - 1	--[c]	477	11	--	14	3	5
2 - 5	--	410	30	--	11	2	13
2 - 9	--	39	48	--	11	5	56
2 - 13	--	24	39	--	12	4	183
2 - 17	--	--	23	--	7	2	56
2 - 21	--	--	17	--	4	0	10
6 - 1	--	800	1	--	11	4	39
6 - 5	--	186	22	--	1	1	14
6 - 9	--	164	47	56	9	90	36
6 - 13	--	28	46	6	0	604	150
6 - 17	--	--	24	--	7	36	42
6 - 21	--	--	8	--	5	13	8
8 - 7	--	458	76	7	41	2	79
8 - 9	--	53	51	16	--	175	228
8 - 11	--	39	60	12	25	1631	22
8 - 13	--	20	113	10	41	1262	19
8 - 15	--	15	117	10	31	454	15
10 - 1	--	456	1	--	12	1	35
10 - 5	--	356	6	18	18	5	38
10 - 7	--	174	19	9	33	2	71
10 - 9	--	49	43	23	69	387	13
10 - 11	--	37	111	370	14	648	20
10 - 13	--	11	16	98	173	3419	4
10 - 15	--	7	45	11	88	2258	5
10 - 17	--	--	24	1	2	55	92
10 - 21	--	--	7	--	14	5	2
12 - 7	--	96	250	3	15	37	111
12 - 9	--	47	39	312	18	102	76
12 - 11	--	34	167	6028	--	592	76
12 - 13	--	17	52	2960	12	271	258
12 - 15	--	32	16	405	8	160	38
14 - 1	--	40	8	1	25	13	9
14 - 5	--	29	3	3	15	4	28
14 - 7	--	107	4	1	30	5	53
14 - 9	--	21	8	302	102	47	13
14 - 11	--	28	3	1038	102	82	38
14 - 13	--	37	15	2709	233	60	136
14 - 15	--	11	7	505	133	4	78
14 - 17	--	--	3	3	115	8	4
14 - 21	--	--	3	8	70	3	5
16 - 7	--	--	7	9	31	10	61
16 - 9	--	--	7	280	26	5	6
16 - 11	--	--	6	584	23	9	5
16 - 13	--	--	5	1215	31	9	5
16 - 15	--	--	11	361	110	6	4
18 - 1	--	--	4	1	14	8	1
18 - 5	--	--	9	1	20	8	4
18 - 9	--	--	12	6	92	7	11
18 - 13	--	--	12	447	228	7	13
18 - 17	--	--	12	9	132	2	6
18 - 21	--	--	8	6	40	7	12
22 - 1	--	--	7	--	0	7	0
22 - 5	--	--	4	3	0	4	14
22 - 9	--	--	1	19	12	2	1
22 - 13	--	--	2	9	64	2	1
22 - 17	--	--	3	8	15	1	5
22 - 21	--	--	4	--	38	5	4
A/B	--	32	4	0	57	1	39
B/C	--	16	38	--	16	11	90
C/D	--	--	--	--	9	2	23
A/D	--	--	7	--	28	3	9

a PET indicates Peterson Sampler
b SS indicates Stainless Steel Sampler
c -- indicates sample not analyzed

Table E.2. Uncorrected Single Fiber Source Strength Estimates for Each Sampler and Its Associated Area, by Trial. (Trial D1 Not Assayed, Therefore Not Included)

Sampler	Associated Area (m^2)	Trial D2 PET	Trial D3 PET	Trial S1 PET[a]	Trial S1 SS[b]	Trial S2 PET	Trial S2 SS
2 - 1	100	26,776,726	617,493	--	96,685	168,408	34,530
2 - 5	100	23,015,636	1,684,071	--	75,967	112,272	89,779
2 - 9	100	2,189,292	2,694,513	--	75,967	280,680	386,740
2 - 13	100	1,347,257	2,189,292	--	82,973	224,544	1,263,812
2 - 17	100	--	1,291,121	--	48,342	112,272	386,740
2 - 21	100	--	954,307	--	27,624	0	69,061
6 - 1	100	44,908,558	56,136	--	75,967	224,544	269,337
6 - 5	93.75	9,788,662	1,157,799	--	6,474	52,526	90,642
6 - 9	75	6,904,691	1,978,783	2,358,226	46,616	3,789,180	186,464
6 - 13	75	1,178,850	1,936,682	252,667	0	25,429,608	776,934
6 - 17	93.75	--	1,263,052	--	45,321	1,894,590	271,927
6 - 21	100	--	449,086	--	34,530	729,768	55,249
8 - 7	25	6,427,537	1,066,578	98,259	70,787	28,068	136,395
8 - 9	25	743,798	715,738	224,593	62,155	2,455,950	392,928
8 - 11	25	547,323	842,035	168,445	43,163	22,889,454	37,983
8 - 13	25	280,678	1,585,833	140,370	70,787	17,710,908	32,804
8 - 15	25	210,509	1,641,969	140,370	53,522	6,371,436	25,898
10 - 1	100	25,597,878	56,136	--	82,872	56,136	241,713
10 - 5	75	14,988,321	252,611	758,001	93,232	210,510	196,823
10 - 7	25	2,441,903	266,644	126,334	56,975	28,068	122,583
10 - 9	25	687,662	603,459	322,852	119,129	5,431,158	22,445
10 - 11	25	519,255	1,557,766	5,193,711	24,171	9,094,032	34,530
10 - 13	25	154,373	224,543	1,375,632	298,678	47,982,246	6,906
10 - 15	25	98,237	631,527	154,408	151,934	31,688,772	8,632
10 - 17	75	--	1,010,442	42,111	10,359	2,315,610	476,519
10 - 21	100	--	392,950	--	96,685	280,680	13,812
12 - 7	25	1,361,291	3,508,481	42,111	25,898	519,258	191,644
12 - 9	25	659,594	547,323	4,379,562	31,077	1,431,468	131,215
12 - 11	25	477,153	2,343,665	84,615,385	153,660	8,308,128	131,215
12 - 13	25	238,577	729,764	41,549,691	20,718	3,803,214	445,442
12 - 15	25	449,086	224,543	5,685,008	13,812	2,245,440	65,608
14 - 1	100	2,245,428	449,086	56,148	172,652	729,768	62,155
14 - 5	75	1,220,951	126,305	126,334	77,693	168,408	145,028
14 - 7	25	1,501,630	56,136	14,037	51,796	70,170	91,506
14 - 9	25	294,712	112,271	4,239,191	176,105	659,598	22,445
14 - 11	25	392,950	42,102	14,570,466	176,105	1,150,788	65,608
14 - 13	25	519,255	210,509	38,026,396	402,279	842,040	234,807
14 - 15	25	154,373	98,237	7,088,714	229,627	56,136	134,668
14 - 17	75	--	126,305	126,334	782,113	336,816	20,718
14 - 21	100	--	168,407	449,186	483,425	168,408	34,503
16 - 7	25	--	98,237	126,334	53,522	140,340	105,318
16 - 9	25	--	98,237	3,930,376	44,890	70,170	10,359
16 - 11	25	--	84,204	8,197,642	39,710	126,306	8,632
16 - 13	25	--	70,170	17,055,025	53,522	126,306	8,632
16 - 15	25	--	154,373	5,067,378	189,917	84,204	6,906
18 - 1	100	--	224,543	56,148	96,685	449,088	6,906
18 - 5	93.75	--	473,645	52,639	129,489	421,020	32,372
18 - 9	75	--	505,221	252,667	476,519	294,714	56,957
18 - 13	75	--	505,221	18,823,694	1,180,939	294,714	67,334
18 - 17	93.75	--	505,221	473,751	854,627	105,255	38,847
18 - 21	100	--	449,086	336,889	276,243	393,952	82,873
22 - 1	100	--	392,950	--	0	393,952	0
22 - 5	100	--	224,543	168,445	0	224,544	96,685
22 - 9	100	--	56,136	1,066,816	82,873	112,272	6,906
22 - 13	100	--	112,271	505,334	441,989	112,272	6,906
22 - 17	100	--	168,407	449,186	103,591	56,136	34,530
22 - 21	100	--	224,543	--	262,431	280,680	27,624
A/B	79.8	1,433,484	179,185	0	314,130	44,796	214,931
B/C	79.8	716,742	1,702,263	--	88,176	492,760	495,996
C/D	79.8	--	--	--	49,600	89,592	126,754
A/D	79.8	--	313,575	--	154,310	134,389	49,600
Totals		185,764,420	43,599,109	276,866,730	9,806,218	210,543,880	9,109,824
		1.86×10^{8}	0.44×10^{8}	2.77×10^{8}	9.80×10^{6}	2.10×10^{8}	9.11×10^{6}
Corrected value[d]		(3.9×10^{8})[d]	(0.9×10^{8})[d]	(2.9×10^{8})[d]	(0.2×10^{8})[d]	(2.2×10^{8})[d]	(0.2×10^{8})[d]

[a] PET indicates Peterson Sampler
[b] SS indicates Stainless Steel Mesh Sampler
[c] -- indicates sample not analyzed
[d] corrected totals for sampler efficiency and plume direction of 60° for Trials D-2 and D-3, 0° for Trials S-1 and S-2.

Table E.3. Source Strength of Carbon Fiber Clumps Computed from Overhead Array, Carbon Fiber Pool Tests. Trials D-2, D-3, S-1 and S-2.

Size Category (No. of Fibers/Clump)	Number of Clumps				Percent of Total Number of Clumps			
	D-2	D-3	S-1	S-2	D-2	D-3	S-1	S-2
2 - 5	1.2×10^6	1.2×10^6	0.3×10^6	3.0×10^6	39	74	18	42
6 - 10	0.5×10^6	0.2×10^6	0.3×10^6	1.4×10^6	21	14	17	22
11 - 20	0.3×10^6	0.1×10^6	0.4×10^6	0.9×10^6	9	7	27	14
21 - 50	0.6×10^6	0.7×10^5	0.2×10^6	0.5×10^6	20	5	14	7
51 - 100	0.9×10^5	0.0	0.1×10^6	0.4×10^6	3	0	5	6
101 - 300	0.6×10^5	0.0	0.2×10^6	0.1×10^6	2	0	10	2
301 - 500	0.2×10^6	0.1×10^5	0.1×10^6	0.2×10^6	6	1	5	3
> 500		0.0	0.1×10^6	0.3×10^6		0	4	4
Total	3.1×10^6	1.5×10^6	1.7×10^6	6.8×10^6				
*Corrected total	6.6×10^6	3.2×10^6	1.8×10^6	7.2×10^6				

* Corrected for cosine of plume direction and sampler efficiency.

APPENDIX F. LENGTH AND DIAMETER DISTRIBUTIONS OF CARBON FIBERS ON SAMPLERS, POOL FIRE TEST

Carbon fibers categorized for lengths and diameters on the vertical array were selected randomly from samplers on towers that were in the densest portion of the plume. Approximately 300 fibers (30 on each of 10 samplers) on each trial were sized. Fibers from the overhead canopy stainless steel and "Peterson" samplers were also selected at random. No fibers under 1 mm in length were considered. Length distributions were corrected for a 15.6 percent slippage of fibers in the 1 - 2 mm category and 8.8 percent slippage in the 2 - 3 mm category. Diameter distributions were calculated from original data, without correction.

The mean length of fibers collected on the vertical array from random samples at various levels was 4.8 mm. The mean length of fibers from the 1.52-m height and 53.34-m height was 4.2 mm and 3.2 mm, respectively. Previous experience in sizing fibers from burned composite material indicated a high degree of variability, with the standard deviation being >50 percent of the mean on most tests and sometimes as great as the mean. Considering the variability associated with the mean length on a test, mean fiber length on the entire vertical array was not significantly different from mean lengths at the 1.52-m and 53.34-m heights for stainless steel samplers on the vertical array.

Table F.1. Length Distribution of Single Carbon Fibers on Stainless Steel Mesh Samplers, Pool Fire Test.

Length Category (mm)	Percent of Total				
	Vertical Array			Overhead Array	
	D-1[a]	D-2	D-3	S-1	S-2
1-<2	14.2	18.6	16.4	35.7	45.2
2-<3	21.1	21.0	15.9	32.3	29.4
3-<4	14.4	20.5	12.0	9.2	12.9
4-<5	12.5	8.1	12.0	10.1	4.2
5-<6	8.2	11.0	8.2	2.8	3.2
6-<7	3.8	5.7	8.6	4.6	2.3
7-<8	7.7	3.8	6.2	0.9	0.9
8-<9	6.7	1.9	7.2	0.9	0.5
9-<10	1.9	2.4	1.4	0.0	0.5
10-<11	1.4	0.5	2.4	0.0	0.0
11-<12	2.4	1.0	1.4	0.0	0.0
12-<13	2.4	0.5	1.4	0.0	0.0
13-<14	0.5	0.5	1.0	0.0	0.0
14-<15	0.5	0.5	0.5	0.0	0.0
15-<16	0.5	0.0	0.5	0.0	0.5
16-<17	0.5	0.5	0.0	1.8	0.0
17-<18	0.0	1.4	1.0	0.0	0.0
18-<19	0.0	1.0	1.0	0.9	0.0
19-<20	1.0	0.0	1.0	0.0	0.5
>20	0.5	1.4	1.9	0.9	0.0
Mean Length	5.0	4.4	5.2	3.2	2.7

[a] D-1, D-2, D-3, S-1, and S-2 are trial designations.

Table F.2. Diameter Distribution of Single Carbon Fibers on Stainless Steel Mesh Samplers, Pool Fire Test.

Diameter Category (μm)	Percent of Total				
	Vertical Array			Overhead Array	
	D-1[a]	D-2	D-3	S-1	S-2
1-<2	0	1	2	3	0
2-<3	15	15	10	13	17
3-<4	19	22	30	33	28
4-<5	28	29	43	34	30
5-<6	17	20	11	11	20
6-<7	14	12	3	4	4
7-<8	7	1	1	2	1
8-<9	0	0	0	0	0
9-<10	0	0	0	0	0
>10	0	0	0	0	0
Mean Diameter	4.7	4.4	4.1	4.1	4.2

[a]D-1, D-2, D-3, S-1, and S-2 are trial designations.

Table F.3. Length Distribution of Single Carbon Fibers from Stainless Steel Mesh Samplers from Specific Heights on Vertical Array, Pool Fire Test.

Length Category (mm)	Percent of Total					
	1.52 m (5 ft)			53.34 m (175 ft)		
	D-1[a]	D-2	D-3	D-1	D-2	D-3
1-<2	4.58	5.74	23.34	24.11	18.62	39.92
2-<3	24.56	19.28	24.86	37.80	47.98	27.16
3-<4	26.21	25.32	16.01	13.00	11.14	13.72
4-<5	20.38	11.68	12.24	4.64	9.23	9.14
5-<6	6.79	10.71	11.30	4.64	7.42	6.40
6-<7	8.74	7.79	3.77	1.86	1.86	2.74
7-<8	2.91	11.68	4.71	2.79	0.93	0.00
8-<9	1.94	2.92	0.94	0.93	0.00	0.00
9-<10	0.97	0.00	1.88	4.64	0.93	0.00
10-<11	2.91	0.00	0.94	3.72	0.00	0.91
11-<12	0.00	3.89	0.00	1.86	0.00	0.00
12-<13	0.00	0.00	0.00	0.00	0.93	0.00
13-<14	0.00	0.97	0.00	0.00	0.93	0.00
14-<15	0.00	0.00	0.00	0.00	0.00	0.00
15-<16	0.00	0.00	0.00	0.00	0.00	0.00
16-<17	0.00	0.00	0.00	0.00	0.00	0.00
17-<18	0.00	0.00	0.00	0.00	0.00	0.00
18-<19	0.00	0.00	0.00	0.00	0.00	0.00
19-<20	0.00	0.00	0.00	0.00	0.00	0.00
>20						
Mean Length	4.2	4.8	3.7	3.7	3.2	2.8

[a]D-1, D-2, and D-3 are trial designations.

Table F.4. Length Distribution of Single Carbon Fibers on Stainless Steel Mesh Samplers, by Downwind Row, Pool Fire Test.

Length Category (mm)	Percent of Total		
	Row AA	Row BB	
	D-2[a]	D-1	D-3
1-<2	16.89	11.83	26.88
2-<3	22.04	29.42	32.21
3-<4	19.03	20.06	17.20
4-<5	14.31	8.12	8.83
5-<6	6.68	8.60	4.18
6-<7	1.43	5.73	2.79
7-<8	7.63	3.82	2.32
8-<9	1.43	1.43	1.86
9-<10	2.39	3.34	1.39
10-<11	1.91	2.39	0.46
11-<12	0.48	1.91	0.46
12-<13	0.95	0.00	0.00
13-<14	0.48	0.00	0.00
14-<15	0.95	0.96	0.00
15-<16	0.48	0.96	0.00
16-<17	0.00	0.00	0.46
17-<18	0.95	0.00	0.00
18-<19	0.00	0.00	0.00
19-<20	0.95	0.00	0.00
>20	0.95	0.95	0.93
Mean Length	4.3	4.5	3.3

[a]D-1, D-2, and D-3 are trial designations.

Table F.5. Diameter Distribution of Single Carbon Fibers on Stainless Steel Mesh Samplers Downwind, Pool Fire Test.

Diameter Category (um)	Percent of Total		
	Row AA	Row BB	
	D-2[a]	D-1	D-3
1-<2	1.00	2.00	0.00
2-<3	9.00	5.00	14.00
3-<4	22.00	8.00	23.00
4-<5	34.00	26.00	35.00
5-<6	18.00	27.00	17.00
6-<7	10.00	21.00	6.00
7-<8	8.00	5.00	3.00
8-<9	1.00	2.00	2.00
9-<10	1.00	0.00	0.00
>10	0.00	0.00	0.00
Mean Diameter	4.6	5.3	4.4

[a]D-1, D-2, and D-3 are trial designations.

Table F.6. Length Distribution of Single Carbon Fibers on Nylon Mesh Samplers at Downwind Rows, Pool Fire Test, Trial D-3, 9 November 1979.

Length Category (mm)	Percent of Total						
	Row DD	Row FF	Row Z	Row X	Row V	Row P	Row B
1-<2	43.98	48.44	51.41	41.94	47.31	0.00	19.62
2-<3	31.59	23.73	26.14	30.41	12.60	68.75	30.49
3-<4	11.61	12.52	3.96	3.95	17.18	31.25	11.09
4-<5	4.28	6.26	5.28	0.00	11.45	0.00	5.54
5-<6	3.97	4.17	1.32	7.90	5.73	0.00	0.00
6-<7	0.61	1.39	2.64	7.90	0.00	0.00	5.54
7-<8	1.22	0.70	0.00	7.90	0.00	0.00	11.09
8-<9	1.53	0.00	1.32	0.00	0.00	0.00	0.00
9-<10	0.31	0.70	0.00	0.00	0.00	0.00	5.54
10-<11	0.31	0.70	1.32	0.00	0.00	0.00	5.54
11-<12	0.00	0.70	2.64	0.00	0.00	0.00	5.54
12-<13	0.61	0.70	1.32	0.00	0.00	0.00	0.00
13-<14	0.00	0.00	0.00	0.00	5.73	0.00	0.00
14-<15	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15-<16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16-<17	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17-<18	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18-<19	0.00	0.00	1.32	0.00	0.00	0.00	0.00
19-<20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
>20	0.00	0.00	1.32	0.00	0.00	0.00	0.00
Mean Length	2.9	3.0	3.7	3.4	3.5	3.0	4.9

Table F.7. Length Distribution of Single Carbon Fibers on "Peterson" Samplers from Overhead Array, Pool Fire Test.

Length Category (mm)	Percent of Total				
	D-1[a]	D-2	D-3	S-1	S-2
1-<2	48.57	38.46	42.65	33.33	44.18
2-<3	24.29	24.61	27.49	21.40	20.48
3-<4	12.86	12.31	15.64	14.81	12.85
4-<5	8.57	6.15	5.21	15.23	6.83
5-<6	2.86	6.15	2.84	6.17	2.81
6-<7	1.43	6.15	3.79	4.12	3.21
7-<8	0.00	4.62	1.42	0.82	2.41
8-<9	0.00	1.54	0.00	0.41	1.61
9-<10	0.71	0.00	0.00	1.23	0.80
10-<11	0.00	0.00	0.47	0.00	1.61
11-<12	0.71	0.00	0.00	1.23	0.80
12-<13	0.00	0.00	0.00	0.00	0.00
13-<14	0.00	0.00	0.47	0.00	0.00
14-<15	0.00	0.00	0.00	0.41	0.80
15-<16	0.00	0.00	0.00	0.00	0.00
16-<17	0.00	0.00	0.00	0.00	0.40
17-<18	0.00	0.00	0.00	0.00	0.00
18-<19	0.00	0.00	0.00	0.00	0.00
19-<20	0.00	0.00	0.00	0.00	0.00
>20	0.00	0.00	0.00	0.82	0.40
Mean Length	2.6	3.12	2.7	3.3	3.2

[a]D-1, D-2, D-3, S-1, and S-2 are trial designations.

Table F.8. Diameter Distribution of Single Carbon Fibers on "Peterson" Samplers from Overhead Array, Pool Fire Test.

Diameter Category (μm)	Percent of Total				
	D-1	D-2	D-3	S-1	S-2
1-<2	2.81	5.94	3.94	1.00	4.00
2-<3	16.49	20.13	31.54	12.00	8.00
3-<4	22.46	21.45	31.54	22.00	15.00
4-<5	25.61	29.37	23.30	22.00	34.00
5-<6	13.68	13.20	5.73	26.00	23.00
6-<7	7.02	6.27	2.87	9.00	13.00
7-<8	3.51	1.98	0.36	8.00	1.00
8-<9	5.61	1.32	0.72	0.00	2.00
9-<10	2.11	0.33	0.00	0.00	0.00
>10	0.70	0.00	0.00	0.00	0.00
Mean Diameter	4.5	4.1	3.6	4.7	4.6

[a]D-1, D-2, D-3, S-1, and S-2 are trial designations.

APPENDIX G. METEOROLOGICAL DATA

1. Meteorological tower MT was located approximately 30 m northeast of the north fire pool.

2. Meteorological tower T-NO was located 9.7 km (6 mi) downwind of the fire site.

3. Meteorological tower T-SO was located 16.1 km (10 mi) downwind of the fire site.

Table G.1. Meteorological Data for Carbon Fiber Pool Fire Test, Tower MT.

Trial	Date (1979)	Z Time (Ignition) (MST)	Burn Time (Flame Out) (min)	Time (min)	2-m Level HWD[a] (°)	2-m Level WS[b] (m/sec)	8-m Level HWD[a] (°)	8-m Level WS[b] (m/sec)	16-m Level HWD (°)	16-m Level VWD[c] (°)	16-m Level WS (m/sec)	32-m Level HWD (°)	32-m Level VWD (°)	32-m Level WS (m/sec)	60-m Level HWD (°)	60-m Level VWD (°)	60-m Level WS (m/sec)	Temperature (°C)	Humidity (%)
D - 1	26 Oct	1503:10	1522	Z to Z + 5	350.4	5.7	354.7	6.7	350.5	-1.1	7.3	348.6	1.6	7.7	345.4	-1.1	8.1	15.6	39
				+ 10	358.8	5.6	003.1	6.6	358.7	-1.9	7.1	356.9	0.3	7.6	354.2	-1.7	7.9		
				+ 15	355.6	5.5	000.9	6.7	357.9	-0.6	7.5	357.0	1.7	8.1	354.9	-0.5	8.4		
				+ 20	358.5	5.2	004.3	5.9	001.0	-3.0	6.5	358.9	-1.7	6.9	358.5	-6.2	7.5		
				+ 25	001.8	6.0	006.1	7.1	002.4	-1.2	7.6	000.4	0.6	8.1	356.0	-1.5	8.5		
D - 2	31 Oct	0940:58	1001	Z to Z + 5	296.8	5.2	299.5	5.9	293.9	0.0	5.8	291.8	5.2	5.8	289.2	ND[d]	5.9	3.9	77
				+ 10	294.4	4.9	295.7	5.5	293.4	-2.9	5.2	291.8	2.2	5.4	290.2	ND	5.9		
				+ 15	297.1	5.4	299.4	6.0	296.6	1.1	6.0	295.7	4.5	6.2	295.0	ND	6.4		
				+ 20	304.0	4.9	303.9	5.6	301.1	-0.6	5.6	297.7	1.9	5.7	297.7	ND	5.7		
				+ 25	292.6	4.3	296.6	5.0	300.3	-2.2	5.0	300.1	0.4	5.4	302.0	ND	5.8		
D - 3	09 Nov	1231:10	1254	Z to Z + 5	320.3	4.7	320.3	5.2	319.8	-3.2	5.4	320.0	0.0	5.7	319.1	-0.4	6.2	10.2	40
				+ 10	329.5	4.5	329.1	5.0	327.9	-1.0	5.1	325.5	2.7	5.3	321.0	1.0	5.5		
				+ 15	330.5	4.9	330.9	5.7	332.0	-1.1	5.9	330.2	1.3	6.2	327.1	0.6	6.4		
				+ 20	327.9	4.2	325.9	4.8	327.1	-3.5	5.0	325.0	-2.4	5.3	324.8	-6.6	5.7		
				+ 25	333.1	4.4	334.2	5.1	339.3	-0.3	5.4	340.7	1.5	5.8	338.1	0.0	6.1		
S - 1	15 Nov	0855:59	0924	Z to Z + 5	ND	0.3	ND	0.4	ND	ND	0.4	ND	ND	0.6	114.6	ND	1.3	-1.9	75
				+ 10	ND	0.7	ND	0.6	95.3	ND	0.4	126.7	ND	0.3	106.2	ND	1.0		
				+ 15	70.5	0.9	46.9	1.0	83.0	-0.4	0.9	77.1	-10.9	0.9	101.4	ND	1.1		
				+ 20	73.9	0.9	51.7	1.0	89.9	ND	0.9	79.3	ND	1.0	101.8	ND	1.3		
				+ 25	87.0	0.9	70.7	1.0	95.4	ND	0.9	80.3	ND	0.9	98.5	ND	1.2		
S - 2	28 Nov	0856:58	0922	Z to Z + 5	351.0	1.6	353.9	ND	347.8	-1.4	1.8	340.5	2.2	1.9	310.7	-5.9	2.2	-8.7	80
				+ 10	344.8	1.3	346.8	ND	338.1	0.1	1.5	334.1	3.3	1.5	310.6	-6.0	1.8		
				+ 15	338.7	1.0	339.7	ND	328.5	1.5	1.2	327.7	4.4	1.1	310.4	-6.2	1.3		
				+ 20	332.5	0.8	332.6	ND	318.8	2.9	0.8	321.3	5.6	0.7	310.3	-6.4	0.9		
				+ 25	327.3	0.9	318.7	ND	318.7	2.5	0.8	330.1	6.7	0.7	306.0	4.3	0.6		

[a]HWD - Horizontal wind direction
[b]WS - Wind speed
[c]VWD - Vertical wind direction
[d]ND - No data.

Table G.2. Meteorological Data for Carbon Fiber Pool Fire Test, Tower NO.

Trial	Date (1979)	Time (min)	16-m Level HWD[a] (°)	16-m Level WS[b] (m/sec)	32-m Level HWD (°)	32-m Level WS (m/sec)
D - 1	26 Oct	No Data Collected During Trial D - 1				
D - 2	31 Oct	Z to Z + 5	280.3	7.2	303.6	7.4
		+ 10	282.1	7.5	305.4	7.9
		+ 15	284.6	7.2	304.8	7.7
		+ 20	285.6	6.7	307.5	7.1
		+ 25	282.2	6.5	307.5	6.6
		+ 30	287.8	6.9	308.2	7.1
		+ 35	288.4	6.3	307.1	6.5
		+ 40	281.4	6.7	303.6	7.0
		+ 45	280.7	6.5	303.6	6.6
		+ 50	287.2	6.5	308.5	6.7
		+ 55	288.2	6.9	304.5	7.0
		+ 60	280.7	6.4	308.3	6.7
D - 3	09 Nov	Z to Z + 5	319.2	6.3	324.4	6.6
		+ 10	311.5	5.6	327.0	5.7
		+ 15	300.5	6.4	317.1	6.7
		+ 20	330.5	5.6	345.2	5.8
		+ 25	330.3	5.5	344.6	5.9
		+ 30	334.0	6.0	350.1	6.4
		+ 35	332.9	6.4	347.9	6.6
		+ 40	329.5	6.9	340.1	7.2
		+ 45	320.2	6.1	333.4	6.3
		+ 50	323.9	5.5	335.5	5.9
		+ 55	325.5	5.2	357.7	5.4
		+ 60	320.1	5.3	356.0	5.5
S - 1	15 Nov	Z to Z + 5	115.5	0.8	ND[c]	0.7
		+ 10	105.9	0.9	ND	0.9
		+ 15	106.1	0.8	129.4	0.8
		+ 20	079.5	0.7	ND	0.8
		+ 25	063.1	1.0	ND	0.9
		+ 30	085.8	0.9	ND	0.9
		+ 35	ND	0.8	ND	0.8
		+ 40	089.5	0.9	ND	0.9
		+ 45	091.8	0.8	099.0	0.8
		+ 50	078.7	1.0	118.5	0.8
		+ 55	ND	0.9	ND	0.9
		+ 60	087.3	1.0	ND	1.0
S - 2	28 Nov	Z to Z + 5	157.5	1.6	187.7	1.5
		+ 10	152.8	1.5	184.7	1.4
		+ 15	166.9	2.1	198.5	2.0
		+ 20	159.7	2.4	191.7	2.2
		+ 25	164.3	2.3	201.6	2.2
		+ 30	169.0	2.2	200.0	2.1
		+ 35	165.5	1.9	201.6	1.8
		+ 40	158.5	1.9	199.2	1.8
		+ 45	166.2	1.9	198.8	1.9
		+ 50	172.5	2.1	205.0	2.2
		+ 55	173.0	2.0	208.8	1.9
		+ 60	181.7	2.1	210.4	2.0

[a]Horizontal wind direction
[b]Wind speed
[c]No Data

Table G.3. Meteorological Data for Carbon Fiber Pool Fire Test, Tower SO.

			16-m Level		32-m Level	
Trial	Date (1979)	Time (min)	HWD[a] (°)	WS[b] (m/sec)	HWD (°)	WS (m/sec)
D - 1	26 Oct	No Data Collected During Trial D - 1				
D - 2	31 Oct	Z to Z + 5	002.5	6.9	No Data Collected During Trial D - 2	
		+ 10	002.6	7.0		
		+ 15	002.6	7.0		
		+ 20	002.6	7.0		
		+ 25	002.6	7.0		
		+ 30	002.6	7.0		
		+ 35	002.6	7.0		
		+ 40	002.5	7.0		
		+ 45	002.6	7.0		
		+ 50	002.5	6.9		
		+ 55	002.5	6.9		
		+ 60	002.5	5.1		
D - 3	09 Nov	Z to Z + 5	317.9	4.2	333.3	4.2
		+ 10	312.6	5.0	333.0	5.1
		+ 15	305.5	4.5	323.7	5.0
		+ 20	316.8	6.2	336.4	6.4
		+ 25	322.0	5.5	339.3	5.9
		+ 30	322.4	5.9	339.4	6.4
		+ 35	318.7	5.7	336.9	6.0
		+ 40	320.2	4.9	337.4	5.2
		+ 45	324.6	5.3	343.9	5.6
		+ 50	326.0	5.4	342.7	5.9
		+ 55	334.4	5.5	352.4	5.9
		+ 60	329.2	5.3	345.5	5.5
S - 1	15 Nov	Z to Z + 5	162.5	0.9	241.5	1.3
		+ 10	168.9	0.9	234.0	1.3
		+ 15	ND[c]	0.8	232.3	1.3
		+ 20	163.0	0.5	226.7	1.1
		+ 25	095.8	0.5	228.3	0.8
		+ 30	095.7	0.3	225.2	0.7
		+ 35	094.4	0.4	215.7	0.8
		+ 40	103.0	0.6	216.2	0.8
		+ 45	102.2	0.7	188.6	0.8
		+ 50	106.5	0.8	184.0	0.7
		+ 55	122.1	0.8	190.7	0.8
		+ 60	137.7	1.0	189.6	0.7
S - 2	28 Nov	Z to Z + 5	139.3	2.3	128.7	2.3
		+ 10	135.0	2.2	125.0	2.3
		+ 15	144.3	2.2	136.7	2.4
		+ 20	149.1	1.7	139.3	2.0
		+ 25	153.2	1.7	149.1	1.9
		+ 30	157.0	1.7	157.0	1.7
		+ 35	ND	1.5	170.9	1.6
		+ 40	175.4	1.3	169.6	1.4
		+ 45	174.8	1.2	169.8	1.3
		+ 50	175.7	1.2	164.4	1.2
		+ 55	175.4	1.1	171.6	1.1
		+ 60	172.5	0.9	177.1	1.0

[a]HWD - Horizontal wind direction
[b]WS - Wind speed
[c]ND - No data

Table G.4. Pilot Balloon Data for Carbon Fiber Pool Fire Test, Target S Grid Location[a].

Time (min)	Height (m)	Trial D-1, Z[b]- 1503:10 LST Direction (°)	Trial D-1, Z[b]- 1503:10 LST Speed (m/sec)	Trial D-3, Z[b]- 1231:10 LST Direction (°)	Trial D-3, Z[b]- 1231:10 LST Speed (m/sec)
Z + 0.5	108	335	11.3	338	4.4
1.0	216	338	12.3	336	5.0
1.5	315	341	11.6	336	5.5
2.0	414	341	12.3	344	6.3
2.5	513	340	12.0	344	7.4
3.0	612	339	10.2	340	8.6
3.5	706	338	9.6	337	8.0
4.0	801	340	10.0	333	8.5
4.5	894	344	11.3	335	7.5
5.0	990	340	7.4	329	6.6
6.0	1170	334	5.8	322	8.6
7.0	1350	ND	ND	318	10.6
8.0	1530	ND	ND	316	11.7

[a]Approximately 20.9 km (13 mi) downrange of pool fire.
[b]Fire Ignition Time

Table G.5. Pilot Balloon Data for Carbon Fiber Pool Fire Trial D-3, Fire Ignition 1231:10 LST.

		West Vertical[a] R Time[c] - 1240		ASG[b] R Time[c] - 1231	
Time (min)	Height (m)	Direction (°)	Speed (m/sec)	Direction (°)	Speed (m/sec)
Z + 0.5	108	344	10.7	336	5.4
1.0	216	344	8.1	336	6.4
1.5	315	342	6.4	333	8.6
2.0	414	342	6.5	330	9.2
2.5	513	342	4.4	328	8.8
3.0	612	324	3.0	329	11.4
3.5	706	312	4.4	328	15.6
4.0	801	312	8.2	326	11.9
4.5	894	310	12.0	324	15.0
5.0	990	309	13.8	325	23.4
6.0	1170	311	15.7	Balloon burst	
7.0	1350	315	10.2		
8.0	1530	319	18.7		
9.0	1710	320	17.9		
10.0	1890	321	17.6		

[a]Approximately 4.8 km (3 mi) downrange and 4.8 km (3 mi) east of Centerline Road.
[b]Approximately 12.9 km (8 mi) downrange on Centerline Road.
[c]Pilot balloon release time.

Table G.6. Pilot Balloon Data for Carbon Fiber Pool Fire Trial D.2, Fire Ignition Time 0940:58 LST.

Time (min)	Height (m)	ASG[a] R - Time[b] 0948 LST Direction (°)	Speed (m/sec)
R + 0.5	108	317	8.9
1.0	216	318	7.3
1.5	315	316	3.6
2.0	414	319	1.5
2.5	513	306	1.3
3.0	612	270	0.9
3.5	706	239	1.5
4.0	801	255	1.8
4.5	894	269	1.1
5.0	990	256	0.6
6.0	1170	090	0.4
7.0	1350	091	2.0
8.0	1530	097	2.7

[a]Approximately 12.9 km (8 mi) downrange on Centerline Road.
[b]Pilot balloon release time.

Table G.7. Pilot Balloon Data for Carbon Fiber Pool Fire Trials S-1, S-2, West Vertical Grid[a].

		Trial S-1		Trial S-2	
		Z[b] - 1556		Z[b] - 1557	
Time (min)	Height (m)	Direction (°)	Speed (m/sec)	Direction (°)	Speed (m/sec)
Z + 0.5	76	ND	ND	217	1.2
1.0	146	ND	ND	255	1.5
1.5	204	108	0.4	269	2.5
2.0	259	21	1.0	253	1.6
2.5	314	73	0.5	204	1.5
3.0	369	174	2.1	219	1.3
3.5	424	158	3.0	266	1.2
4.0	479	159	4.3	312	1.0
4.5	533	169	4.7	359	1.2
5.0	588	168	4.9	009	1.9
6.0	698	173	4.4	005	2.0
7.0	808	303	0.9	019	1.8
8.0	917	187	2.1	037	1.9
9.0	1027	180	3.3	ND	ND
10.0	1137	185	0.8	ND	ND

[a]Approximately 20.9 km (13 mi) downrange of pool fire.
[b]Fire Ignition Time.

APPENDIX H. MODEL CALCULATIONS FOR TRIAL 3, NASA POOL-FIRE TESTS

Technical Note

MODEL CALCULATIONS FOR TRIAL 3,
NASA POOL-FIRE TRIALS

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SECTION 1
INTRODUCTION

Visual observations of the plumes and measurements of fiber flux made during the NASA Pool-Fire Trials, conducted at DPG, indicate that model calculations of fiber flux (vertical deposition) should be improved if the effluent from the fires is considered to be emitted from two different sources. One source is represented by the hot buoyant plume generated during the time the oil-pool fire is burning intensely and the other source is represented by the warm buoyant plume generated as the oil in the pool is exhausted and the fire dies out. Sampling data from Trial 2 indicate that fibers are released from the smoldering debris after the fire is extinguished. In this technical note, we present the results of a comparison of model estimates of fiber flux, made using both a single source and a double source to represent the oil pool fire plume, with fiber deposition measurements made downwind from the fire during Trial 3 of the NASA Pool-Fire Trials. Trial 3 was selected for these comparisons because it is the only trial in the test series in which the plume was fully contained by the tower and ground sampling network at all distances from the source where flux measurements were made.

The DPG Volume Source Diffusion Models Computer Program[1] was used to calculate the fiber flux for comparison with the measured flux. For the purposes of this report, we present only a discussion of the development of the requisite model inputs (Section 2) and a description of the results of the comparison of the flux calculated by the model with the measurements for Trial 3 (Section 3).

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1 Bjorklund, J. R. and R. K. Dumbauld, 1977: User's instructions for the volume source diffusion models computer program and volume/line source graphics computer program. H. E. Cramer Company, Inc. TR-77-306-01 under Contract No. DAAD09-77-C-0005 with U. S. Army Dugway Proving Ground, Dugway, Utah 84022

SECTION 2
MODEL INPUT PARAMETERS

2.1 METEOROLOGICAL MODEL INPUTS

The meteorological model inputs used in the model were primarily obtained from measurements made on a 60-meter tower located 40 meters north of the pool fire. Wind speed and wind direction were measured at heights of 2, 8, 16, 32 and 60 meters. Wind speed was also measured at a height of 4 meters and vertical wind fluctuations were measured at heights of 16, 32, 48 and 60 meters.

The meteorological inputs required for use in the volume source model are defined in Table 1 and the values used in modeling Trial 3 are given in Table 2. The value of the mean reference wind speed $\bar{u}_R$ at a height z_R of 2 meters and the power-law coefficient p were obtained from a least-squares fit of a wind speed power-law expression to the 20-minute averaged wind speeds measured on the 60-meter tower from ignition (Z) time to twenty-minutes after Z time (Z+20). The standard deviation of the horizontal wind direction $\sigma_A\{\tau_o=600s\}$ in Table 2 represents the average of the two 10-minute values of σ_A measured at a height of 8 meters on the tower between the times Z and (Z+10) and between (Z+10) and (Z+20). In the model calculations, an effective value of σ_A was calculated for each sampling point from the following expression for an average 20-minute σ_A between a height of 8 meters and the plume height at the distance of the sampling point:

$$\sigma_A(eff) = \sigma_A\{\tau_o=600s\} \left(\frac{1200}{600}\right)^{1/5} \left\{\frac{H\{t=x/\bar{u}\}^{(1-p)} - 8^{(1-p)}}{(1-p)(2-p)(H\{t=x/\bar{u}\}-8)}\right\} \quad (1)$$

TABLE 1

METEOROLOGICAL INPUTS REQUIRED FOR THE VOLUME-SOURCE AND PLUME RISE MODELS

Parameter	Description
$\bar{u}_R \{z_R\}$	Mean wind speed at a reference height z_R
p	Power-law coefficient for the wind speed profile
$\sigma_A \{\tau_o\}$	Standard deviation of the horizontal wind fluctuations for a reference measurement time τ_o
σ_E	Standard deviation of the vertical wind fluctuations
H_m	Depth of the surface mixing layer
θ	Mean wind direction
ρ	Ambient air density
T	Ambient air temperature
$\Delta\Phi/\Delta z$	Vertical gradient of ambient potential temperature
α	Crosswind diffusion coefficient
β	Vertical diffusion coefficient

TABLE 2

VALUES OF METEOROLOGICAL PARAMETERS USED IN THE MODEL CALCULATIONS FOR TRIAL 3

Parameter	Value
$\bar{u}_R$ $\{z_R=2m\}$ (m s^{-1})	4.64
p	0.072
σ_A $\{\tau_o=600s\}$ (deg)	10.7
σ_E (deg)	7.2
H_m (m)	900
θ (deg)	323
ρ (g m^{-3})	1044
T (^oK)	283.4
$\Delta\Phi/\Delta z$ (deg m^{-1})	0.005
α	0.9
β	1.0

where $H\{t=x/\bar{u}\}$ is the height of the fiber plume at the downwind distance x to the deposition sampler and $\bar{u}$ is the mean wind transport speed. The height of the plume was calculated from the expression[2]

$$H\{t=x/\bar{u}\} = \begin{cases} \left[\dfrac{3\,F_c}{\bar{u}\,\gamma_c^{\,2}\,s}\quad 1-\cos(s^{1/2}t) \;+\left(\dfrac{r_R}{\gamma_c}\right)^3\right]^{1/3} - \dfrac{r_R}{\gamma_c} & ;\ t \le \pi s^{-1/2} \\[2ex] \left[\dfrac{6\,F_c}{\bar{u}\,\gamma_c^{\,2}\,s} + \left(\dfrac{r_R}{\gamma_c}\right)^3\right]^{1/3} - \left(\dfrac{r_R}{\gamma_c}\right) & ;\ t > \pi s^{-1/2} \end{cases} \qquad (2)$$

where

F_c = buoyancy flux

$$= \frac{g\,Q_c}{\pi\,\rho\,c_p\,T} \qquad (3)$$

g = acceleration due to gravity (9.8 m s^{-1})

Q_c = effective rate of heat release (cal s^{-1})

ρ = ambient air density (g m^{-3})

c_p = specific heat of air (0.24 cal $g^{-1}\ {}^oK^{-1}$)

T = ambient air temperature (^oK)

γ_c = entrainment coefficient

r_R = radius of area covered by burning oil

$$s = \frac{g}{T}\,\frac{\Delta\Phi}{\Delta z} \qquad (4)$$

$\dfrac{\Delta\Phi}{\Delta z}$ = vertical gradient of ambient potential temperature

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2 Briggs, G. A., 1970: Some recent analyses of plume rise observations. Paper ME-8E presented at the Second International Clean Air Congress, Washington, D. C., December 6-11, 1970.

The value for the standard deviation of the vertical wind fluctuations σ_E in Table 2 represents the average value of σ_E measured at a height of 60 meters on the tower over the period Z to (Z+20). The mean wind direction θ in Table 2 is the mean wind direction over the same time period measured at a height of 60 meters. Finally, the depth of the surface mixing layer H_m shown in Table 2 was estimated from pilot balloon measurements of wind direction and wind speed made near the site of the pool fire beginning at Z time.

2.2 SOURCE MODEL INPUTS

Source inputs required by the volume source deposition model and the plume-rise model given by Equation (2) are listed in Table 3 and the values used for calculating deposition for Trial 3 are given in Table 4. We used the measurements from the sampling tower network located 58.8 meters downwind from the pool fire to estimate the source parameters.

We obtained the height of the hot and warm plumes and the values of σ_{zR} for both plumes at the tower network by first summing the fiber counts measured at each height on the tower network across the towers and then used a technique devised by Cohen[3] to fit two normal distributions to the crosswind integrated fiber distribution. The measured and fitted distributions are shown in Figure 1. In the figure, the fiber recoveries are normalized (expressed as a fraction of the total recovery). The chi-square value[3] for the fitted distribution shown in Figure 1 is 0.14. The fitted curve was also used to calculate the percentage of fibers in each plume. The source strength Q for each plume shown in Table 4 was obtained by multiplying the percentage of

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[3] Cohen, A. C., 1967: Estimation in mixtures of two normal distributions. Technometrics, 9, 1, pp. 15-28.

TABLE 3

SOURCE INPUTS REQUIRED FOR THE VOLUME-SOURCE AND PLUME RISE MODELS

Parameter	Description
Q	Effective fiber source strength
σ_{yR} $\{x_{Ry}\}$	Standard deviation of the crosswind distribution of material at the reference distance x_{Ry} downwind from the source
σ_{zR} $\{x_{Rz}\}$	Standard deviation of the vertical distribution of material at the reference distance x_{Rz} downwind from the source
Q_c	Effective heat release rate
r_R	Radius of pool fire
γ_c	Plume entrainment parameter
τ	Source emission time
V_s	Material settling velocity
γ	Fraction of material reflected at the ground

TABLE 4

VALUES OF SOURCE PARAMETERS USED IN THE MODEL CALCULATIONS FOR TRIAL 3

Parameter	Value	
	Hot Plume	Warm Plume
Q (fibers)	4.59×10^7	6.34×10^7
σ_{yR} $\{x_{Ry} = 58.8 \text{ m}\}$ (m)	16.03	16.03
σ_{zR} $\{x_{Rz} = 58.8 \text{ m}\}$ (m)	7.33	7.84
Q_c (g cal s^{-1})	3.390×10^7	2.964×10^6
r_R (m)	5.33	5.33
γ_c	0.66	0.66
τ (s)	1200	1200
V_s (m s^{-1})	0.02	0.02
γ	0.72	0.72

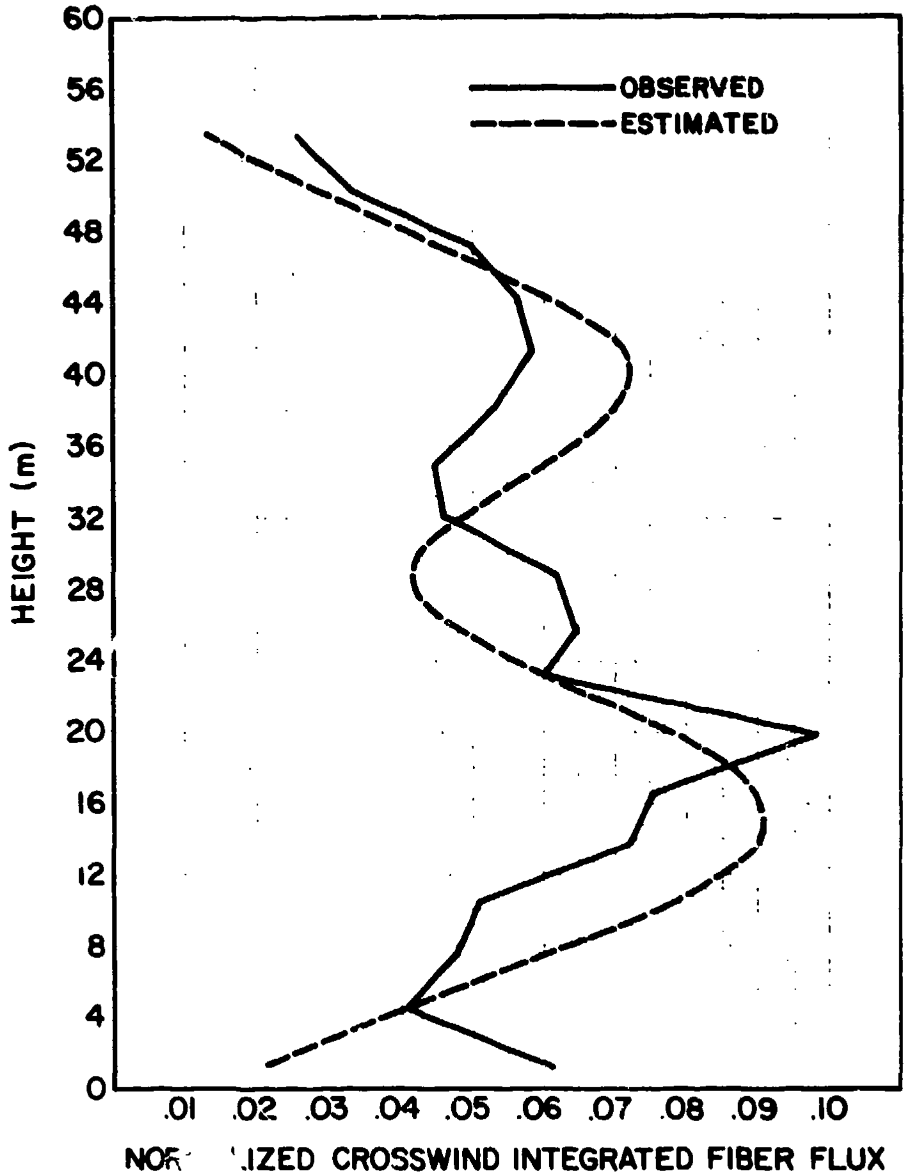

FIGURE 1. ..matd and observed crosswind integrated flux ..easured on the tower network during Trial 3 of the NASA Pool-Fire Trials.

material in each plume by the total number of fibers collected on the tower network. The value of σ_{yR} was obtained from the tower network by summing the measured fiber counts vertically and calculating the cross-wind standard deviation of the vertically integrated fiber distribution.

The values of Q_c used in the plume-rise expression were calculated by solving Equation (2) for the heat required to yield the values of H{t=58.8/4.64=12.7s} for the hot and warm plumes obtained from the estimated flux shown in Figure 1. The calculated value of Q_c calculated for the hot plume by this procedure is approximately 43 percent of the stochiometric values of 7.96×10^7 cal s^{-1} which represents a burning efficiency of 100 percent. Raj[4], in developing a simplified fire model, found that a value of 45 percent for the fraction of entrained air that burns with fuel vapor, yielded the closest agreement between model estimates and measurements made during two fire trials conducted at White Sands Missile Range. The plume entrainment parameter γ_c was set equal to 0.66 for both plumes based on the recommendation given by Briggs[5] and on our prior experience. Heights of the hot and warm plumes at the sampling rows beyond the tower network calculated from the above values for Q_c and γ_c are shown in Table 5. The heights calculated for the hot plume were compared with the plume heights taken from photographs made at 5, 10 and 15 minutes after the fire began. The average plume height from the photographs at 665 meters downwind from the fire was 180 meters and the average plume height at a distance of 1285 meters (the maximum shown in the photographs) was 362 meters. In view of the large uncertainties in the plume heights obtained from the photographs, we believe our calculated plume heights are reasonable.

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4 Raj, P., 1980: Analysis of NASA JP-4 fire tests data and development of a simple fire model. NASA Contractor Report No. 159209, NASA Langley Research Center, Hampton, Va. 23665.

5 Briggs, G. A., 1972: Chimney plumes in neutral and stable surroundings. Atm. Env., 6(7), 507-510.

TABLE 5

CALCULATED PLUME HEIGHTS AT THE DOWNWIND SAMPLING ROWS

Sampling Row	Downwind Distance (m)	Plume Height (m)	
		Hot Plume	Warm Plume
BB	207	95.2	40.0
CC	298	121	52.0
DD	482	163	71.5
EE	665	196	86.6
FF	1,030	240	106
GG	1,398	259	113*
Z	2,206	260*	113
X	3,824	260	113
V	5,421	260	113
P	10,261	260	113
B	19,109	260	113

*Final rise

The value for V_s of 0.02 meters per second was supplied to us by Dugway Proving Ground. The reflection coefficient γ was set equal to 0.72 based on the hypothesis that 28 percent of a material with a settling velocity of 0.02 meters per second is retained at the ground[6].

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6 Boyle, D. G., et al., 1975: DC-7B aircraft spray system for large-area insect control. DPG Document No. DPG-DR-C-980A, U. S. Army Dugway Proving Ground, Dugway, Utah 84022.

SECTION 3

RESULTS OF THE CALCULATIONS FOR TRIAL 3

The results of the model calculations are compared with observations in Figure 2. In Figure 2, the solid line represents the observed crosswind integrated fiber flux obtained by summing the measured flux at all the samplers at a given downwind row and multiplying the result by the separation distance between samplers along that row. Model estimates of the crosswind integrated flux were calculated in a similar manner. That is, the volume source model was used, in conjunction with the input parameters given in Section 2, to estimate the flux at each sampler position and the results summed and multiplied by the sampler separation distance. The dotted curve in the figure represents calculations made using both a hot and warm plume with the source parameters in Table 4. The dashed line represents calculations made assuming the total source strength (1.093×10^8 fibers) was emitted and transported downwind in the hot plume.

Figure 2 shows that the shape of the model curve obtained by using both a hot and warm source more closely resembles the general shape of the crosswind integrated fiber flux than the model curve obtained by using a single hot source. However, the model values of crosswind integrated flux for the two-source case are generally lower by about a factor of two than the corresponding values for the observed flux. In comparing the curves, it should be noted that no single sampler collected more than 5 fibers at the sampling rows beyond 2206 meters from the source and that there are large gaps in the measurements of the crosswind distribution of fibers. For this reason, the observed crosswind fiber flux plotted in Figure 2 at distances beyond 2206 meters is subject to large uncertainty. We are not able to account for the approximate factor-of-two difference between the observed and calculated crosswind integrated flux. Possible explanations of this difference include

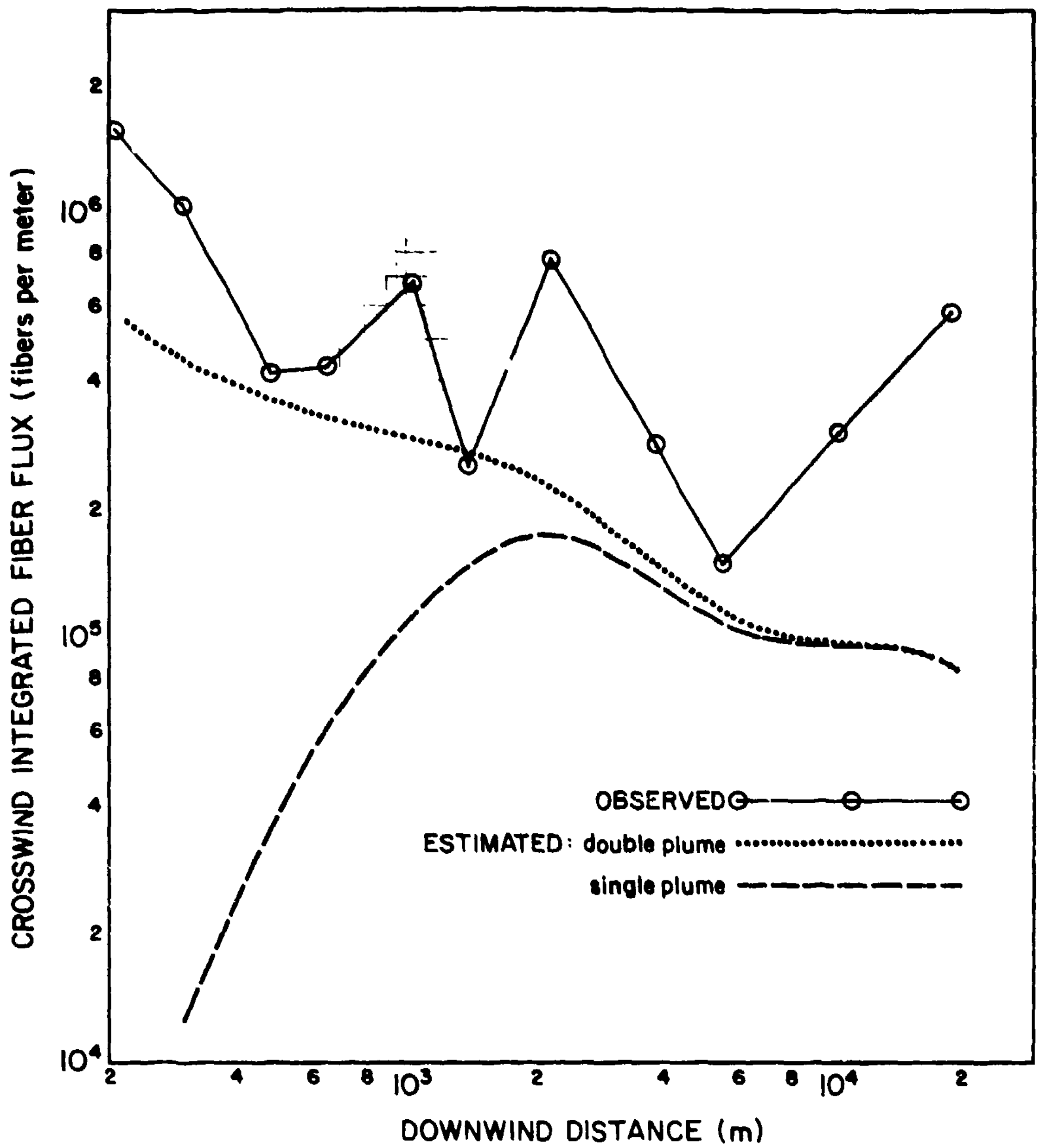


FIGURE 2. Observed and model estimates of crosswind integrated fiber flux (vertical deposition) at sampler height for Trial 3, NASA Pool-Fire Trials.

the collection efficiency of the samplers assumed in establishing the source strength on the tower sampling network may have been in error (see Appendix C of this report), or that resuspension and collection of fibers deposited on the test grid during previous trials of the test series increased the apparent flux measured by the ground sampling network.

Other mechanisms for explaining the observed high levels of fiber flux close to the source can be hypothesized (for example, shedding of fibers from the plume during cloud rise). We believe the model calculations for Trial 3 and the visual observations made during the NASA Pool-Fire Trials indicate that the most likely explanation is the cooling of the plume and the subsequent decrease in buoyant plume rise as the fire dies down. Additional tests in which the plume is fully contained within the sampling network and, if possible, time-dependent measurements of flux are made at a significant number of points, are required to improve the definition of the fiber flux patterns downwind from oil-pool fires.

APPENDIX I. PICTORIAL RECORD OF TIMED PLUME RISE, BY TRIAL

Photographs document the development of the smoke plume from the fire and allow determination of plume height, downwind deployment, and plume dimensions at various times throughout the fire duration. Four 35 mm cameras were placed 1524 m (5000 ft) from the fire pool in the four quadrants (Figure I.1). Each camera's field of view was centered on the fire horizontally and provided approximately a 45° width of coverage. Camera speed was remote-controlled with all shutters operating simultaneously at five pictures per second. A frame-time reference was superimposed on each picture.

Representative pictures taken at 1, 6, 11, 16, and 21 minutes from the start of the fire are presented in Figures I.3 through I.52. These pictures were taken from camera position four, looking downwind, on all five tests; and from one of the two side positions, camera one or camera three (Figure I.1). In Trial D-3 the side camera (position one) was turned horizontally about 15°, placing the fire pool near the edge of the photograph to provide greater coverage of the downwind deployment of the smoke plume.

Three photographic target boards were to have been set up in the field of view of each camera, 100 m (328 ft) in front of the camera centered on the fire pool and 10° [17.6 m (57.7 ft)] to the right and left of the center (for scaling purposes). In many of the photographs, the target boards either cannot be distinguished from the background or were not in place at the time of the trial.

More appropriate scaling factors for the smoke plume in these photographs can be determined from the location of the two balloons supporting the Jacob's Ladder sampling net. Althought the net is not visible in these photographs, its location can be constructed by drawing vertical lines from the balloons to the ground. The elevation of the center of each balloon was 488 m (1600 ft). Balloon lateral spacing was 366 m (1200 ft) between centers and the horizontal distances to the balloon anchor points on the ground can be determined for each camera position from the dimensions given in Figure I.1. In addition, Granite Peak (the mountain in the background) can be used for scale for Trials D-3 and S-1. The highest point on the peak is 851 m (2792 ft) above the desert floor which is essentially level for the portion included in the photographs. The highest point is 10927 m (6.8 mi) horizontally from camera position one (Figure I.2). Using appropriate combinations of the above dimensions, the size and location of any desired portion of the smoke plume can be determined.

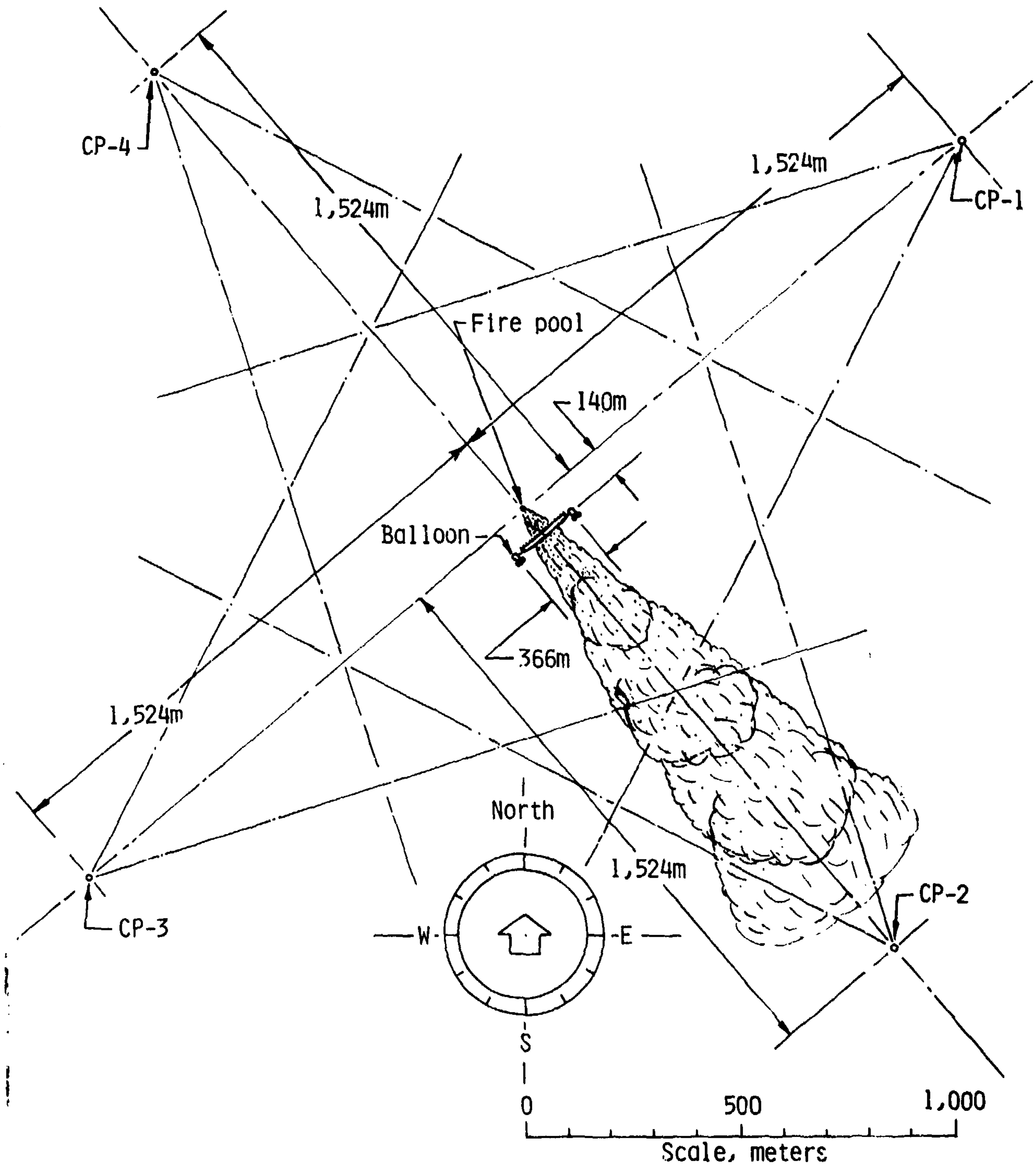


Figure I.1. Camera Positions (CP) and Field of View Used to Provide Smoke Plume Photographic Coverage for Fire-Released Carbon Fiber Test.

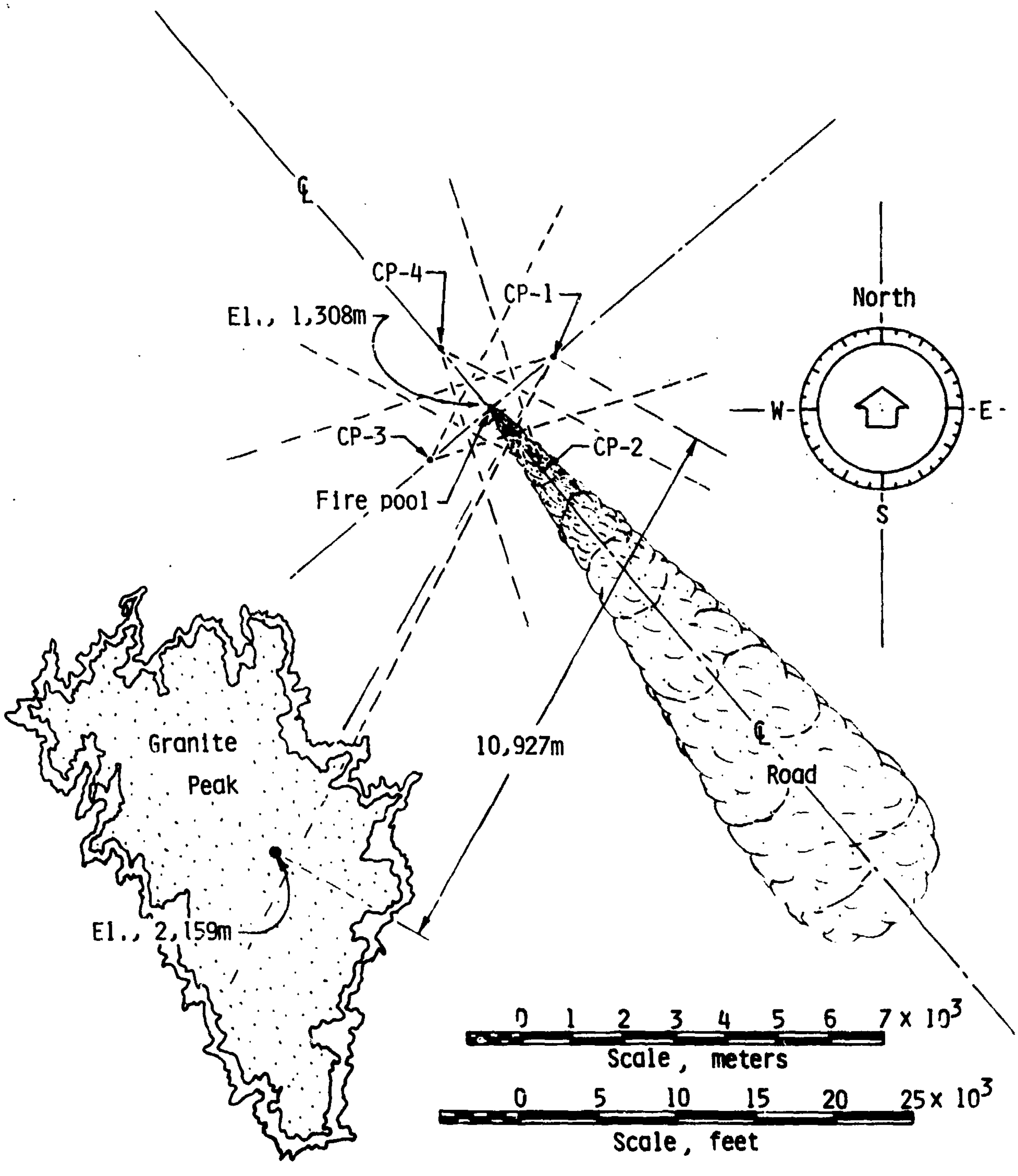


Figure I.2. Camera Positions (CP) in Relation to Granite Peak for Fire-Released Carbon Fiber Tests.

TRIAL D-1 OF CARBON FIBER POOL FIRE TEST

Figures I.3 through I.7. The CP-4 camera was located 1524 m (5000 ft) upwind of the pool center. The camera was aimed southeast.

Figures I.8 through I.12. The CP-3 camera was located 1524 m (5000 ft) southwest of the pool center, on a line perpendicular to the grid center line. The camera was aimed northeast.

Figure I.3 Carbon Fiber Pool Fire Test, Trial D-1, Burn Time Z + One Minute, Camera Position CP-4.

Figure I.4. Carbon Fiber Pool Fire Test, Trial D-1, Burn Time Z + Six Minutes, Camera Position CP-4.

Figure I.5. Carbon Fiber Pool Fire Test, Trial D-1, Burn Time Z + Eleven Minutes, Camera Position CP-4.

Figure I.6. Carbon Fiber Pool Fire Test, Trial D-1, Burn Time Z + Sixteen Minutes, Camera Position CP-4.

Figure I-7. Carbon Fiber Pool Fire Test, Trial D-1, Burn Time Z + Twenty-One Minutes, Camera Position CP-4.

Figure I.8. Carbon Fiber Pool Fire Test, Trial D-1, Burn Time Z + One Minute, Camera Position CP-3.

Figure I.9. Carbon Fiber Pool Fire Test, Trial D-1, Burn Time Z + Six Minutes, Camera Position CP-3.

Figure I.10. Carbon Fiber Pool Fire Test, Trial D-1, Burn Time Z + Eleven Minutes, Camera Position CP-3.

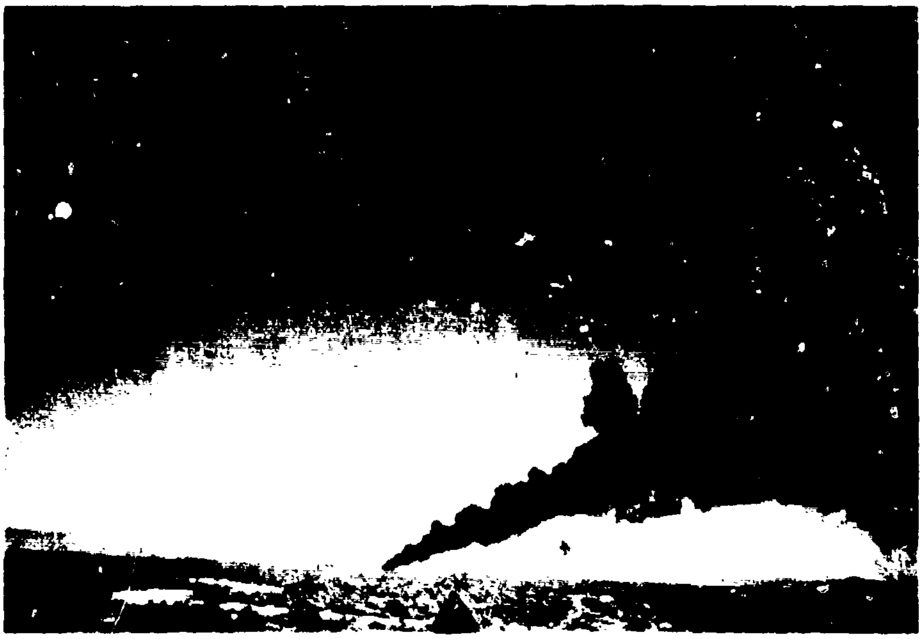


Figure I.11. Carbon Fiber Pool Fire Test, Trial D-1, Burn Time Z + Sixteen Minutes, Camera Position CP-3.

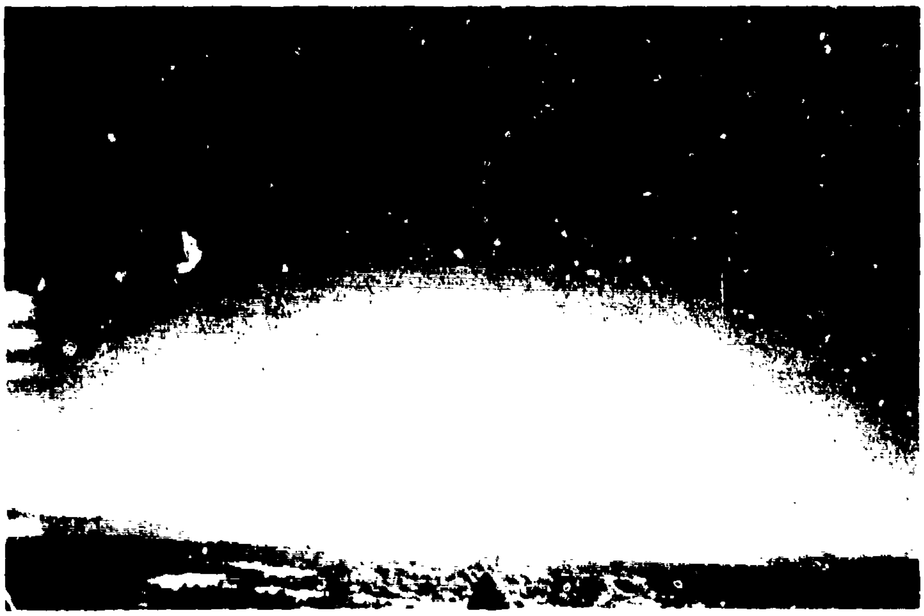


Figure I.12. Carbon Fiber Pool Fire Test, Trial D-1, Burn Time Z + Twenty-One Minutes, Camera Position CP-3.

TRIAL D-2 OF CARBON FIBER POOL FIRE TEST

Figures I.13 through I.17. The CP-4 camera was located 1524 m (5000 ft) upwind of the pool center. The camera was aimed southeast.

Figures I.18 through I.22. The CP-3 camera was located 1524 m (5000 ft) southwest of the pool center, on a line perpendicular to the grid center. The camera was aimed northeast.

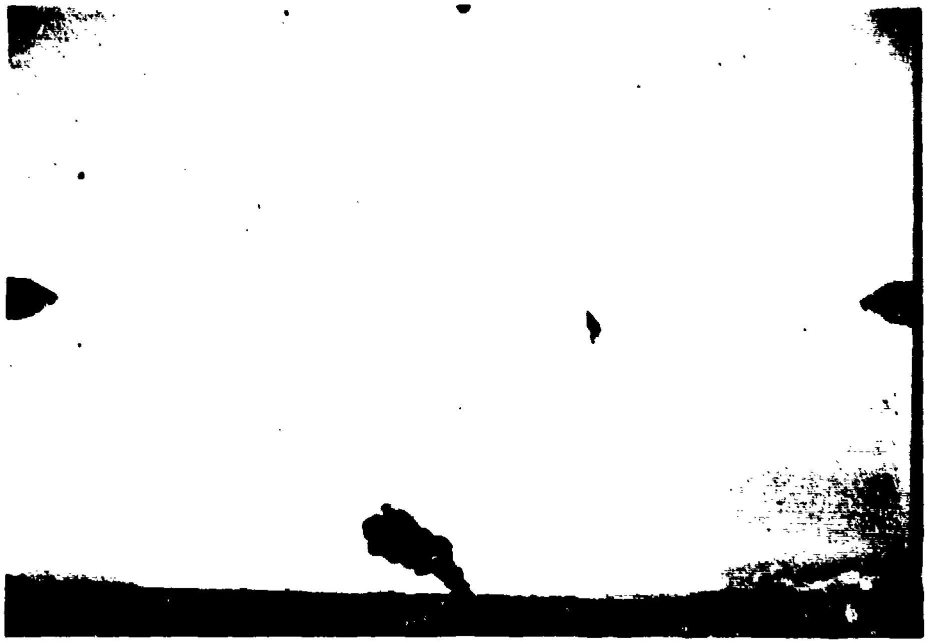


Figure I.13. Carbon Fiber Pool Fire Test, Trial D-2, Burn Time Z + One Minute, Camera Position CP-4.

Figure I.14. Carbon Fiber Pool Fire Test, Trial D-2, Burn Time Z + Six Minutes, Camera Position CP-4.

Figure I.15. Carbon Fiber Pool Fire Test, Trial D-2, Burn Time T + Eleven Minutes, Camera Position CP-4.

Figure I.16. Carbon Fiber Pool Fire Test, Trial D-2, Burn Time T + Sixteen Minutes, Camera Position CP-4.

Figure I.17. Carbon Fiber Pool Fire Test, Trial D-2, Burn Time Z + Twenty-One Minutes, Camera Position CP-4.

Figure I.18. Carbon Fiber Pool Fire Test, Trial D-2, Burn Time Z + One Minute, Camera Position CP-3.

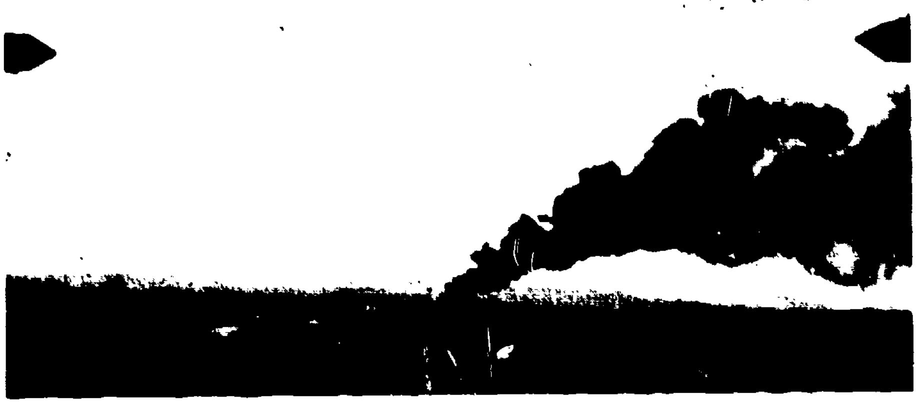


Figure I.19. Carbon Fiber Pool Fire Test, Trial D-2, Burn Time Z + Six Minutes, Camera Position CP-3.

Figure I.20. Carbon Fiber Pool Fire Test, Trial D-2, Burn Time Z + Eleven Minutes, Camera Position CP-3.

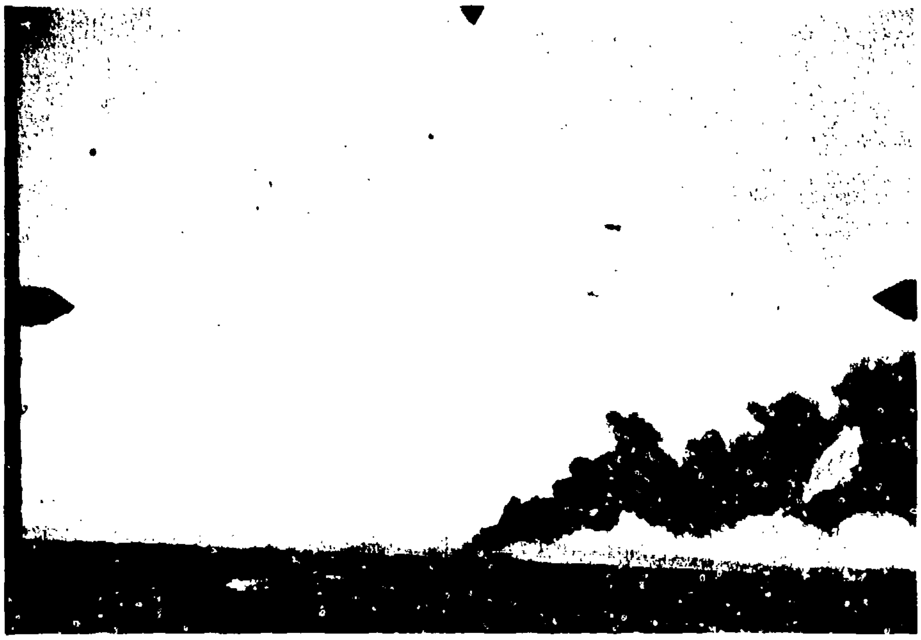


Figure I.21. Carbon Fiber Pool Fire Test, Trial D-2, Burn Time Z + Sixteen Minutes, Camera Position CP-3.

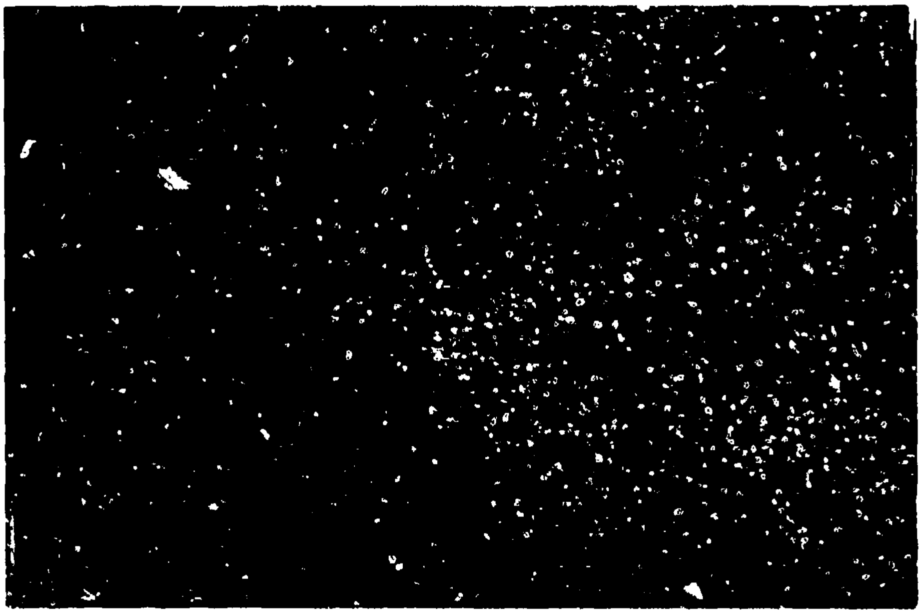


Figure I.22. Carbon Fiber Pool Fire Test, Trial D-2, Burn Time Z + Twenty-One Minutes, Camera Position CP-3.

TRIAL D-3 OF CARBON FIBER POOL FIRE TEST

Figures I.23 through I.27. The CP-4 camera was located 1524 m (5000 ft) upwind of the pool center. The camera was aimed southeast.

Figures I.28 through I.32. The CP-1 camera was located 1524 m (5000 ft) northeast of the pool center, on a line perpendicular to the grid center. The camera was aimed southwest.

Figure I.23. Carbon Fiber Pool Fire Test, Trial D-3, Burn Time Z + One Minute, Camera Position CP-4.

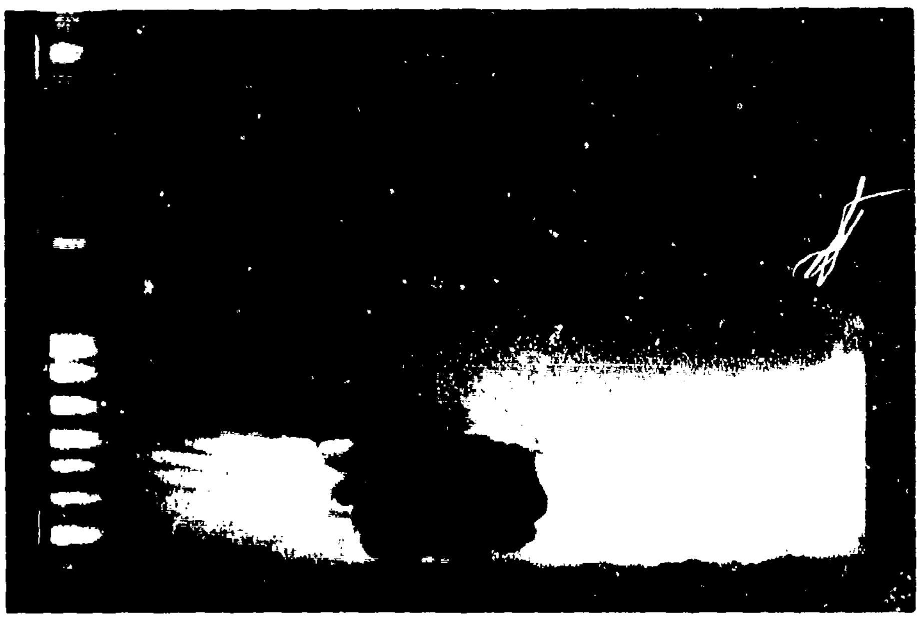


Figure I.24. Carbon Fiber Pool Fire Test, Trial D-3, Burn Time Z + Six Minutes, Camera Position CP-4.

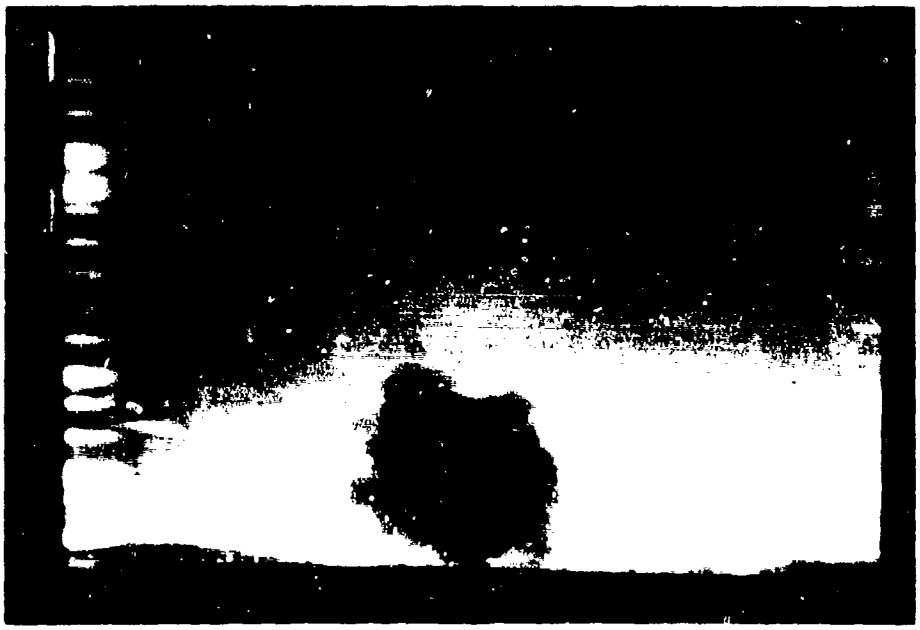


Figure I.25. Carbon Fiber Pool Fire Test, Trial D-3, Burn Time I + Eleven Minutes, Camera Position CP-4.

Figure I.26. Carbon Fiber Pool Fire Test, Trial D-3, Burn Time I + Sixteen Minutes, Camera Position CP-4.

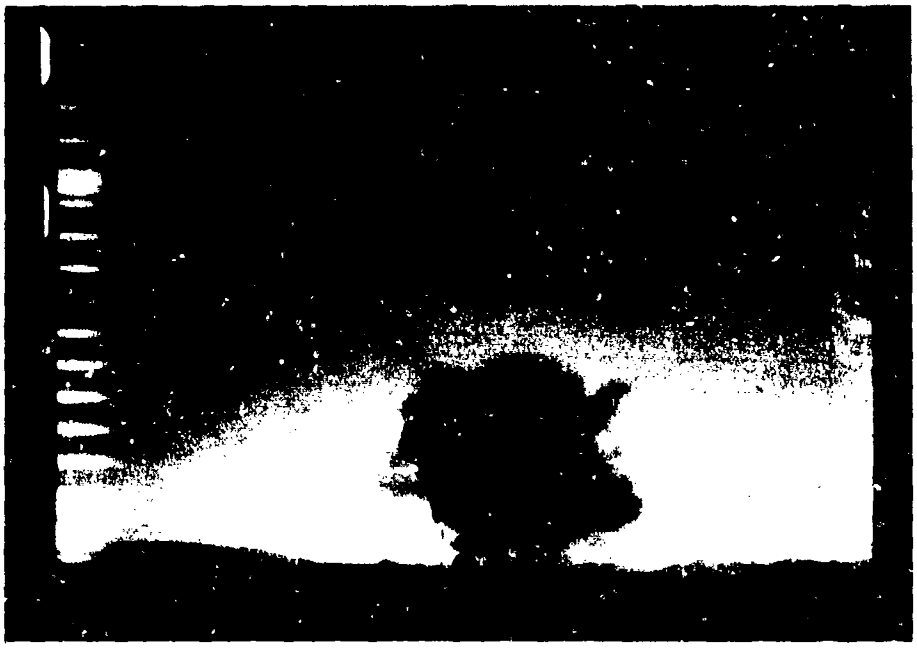


Figure I.27. Carbon Fiber Pool Fire Test, Trial D-3, Burn Time Z + Twenty-One Minutes, Camera Position CP-4.

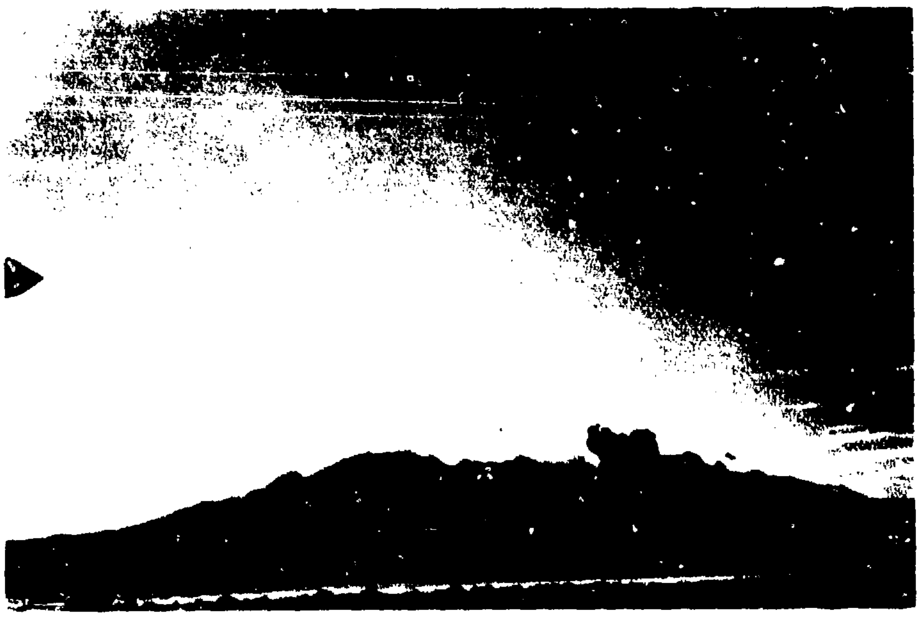


Figure I.28. Carbon Fiber Pool Fire Test, Trial D-3, Burn Time Z + One Minute, Camera Position CP-1.

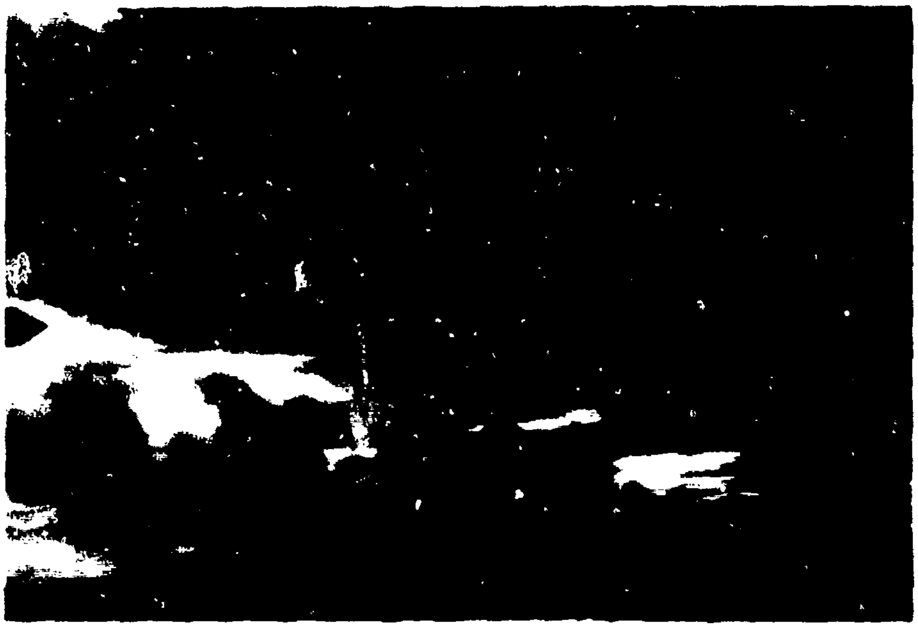


Figure I.29. Carbon Fiber Pool Fire Test, Trial D-3, Burn Time Z + Six Minutes, Camera Position CP-1.

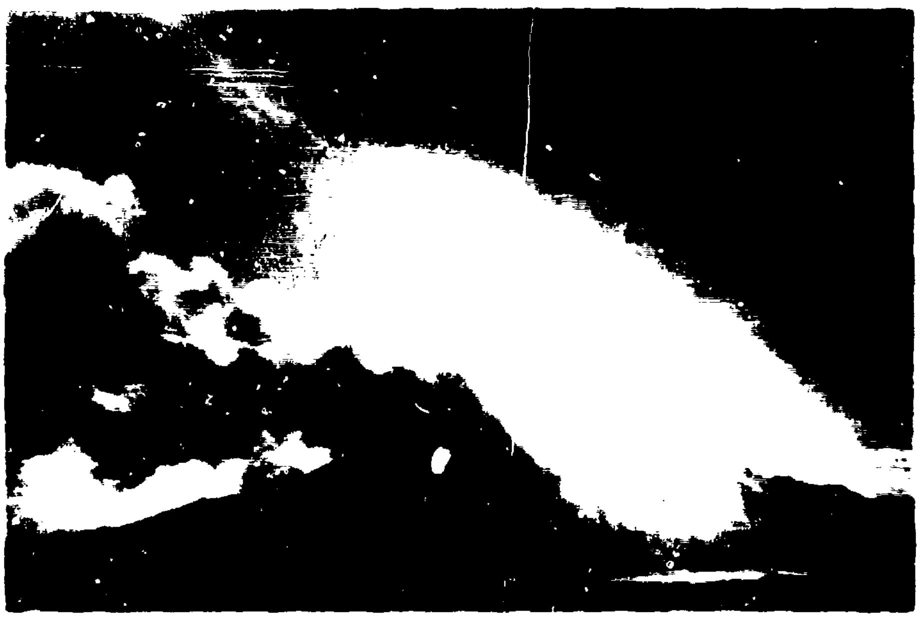


Figure I.30. Carbon Fiber Pool Fire Test, Trial D-3, Burn Time Z + Eleven Minutes, Camera Position CP-1.

Figure I.31. Carbon Fiber Pool Fire Test, Trial D-3, Burn Time T + Sixteen Minutes, Camera Position CP-1.

Figure I.32. Carbon Fiber Pool Fire Test, Trial D-3, Burn Time T + Twenty-One Minutes, Camera Position CP-1.

TRIAL S-1 OF CARBON FIBER POOL FIRE TEST

Figures I.33 through I.37. The CP-3 camera was located 1524 m (5000 ft) southwest of the pool center, on a line perpendicular to grid center. The camera was aimed southeast.

Figures I.38 through I.42. The CP-1 camera was located 1524 m (5000 ft) northeast of the pool center, on a line perpendicular to the grid center. The camera was aimed southwest.

NOTE: Camera CP-4 malfucntioned, therefore Figures I.33 through I.37 were photographed with camera CP-3, directly opposite camera CP-1.

Figure I.33. Carbon Fiber Pool Fire Test, Trial S-1, Burn Time Z + One Minute, Camera Position CP-3.

Figure I.34. Carbon Fiber Pool Fire Test, Trial S-1, Burn Time Z + Six Minutes, Camera Position CP-3.

Figure I.35. Carbon Fiber Pool Fire Test, Trial S-1, Burn Time Z + Eleven Minutes, Camera Position CP-3.

Figure I.36. Carbon Fiber Pool Fire Test, Trial S-1, Burn Time Z + Sixteen Minutes, Camera Position CP-3.

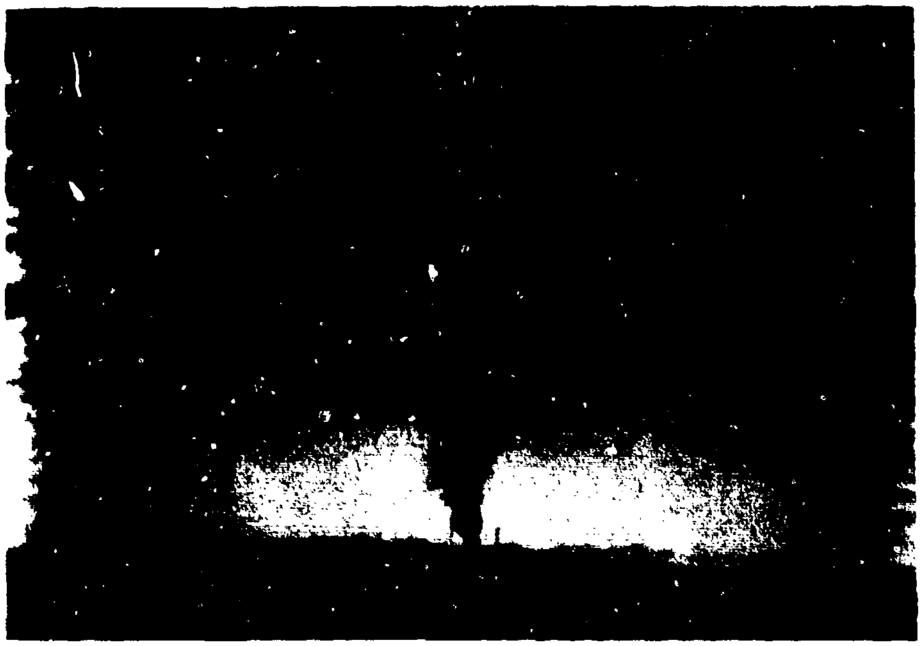


Figure I.37. Carbon Fiber Pool Fire Test, Trial S-1, Burn Time Z + Twenty-One Minutes, Camera Position CP-3.

Figure I.38. Carbon Fiber Pool Fire Test, Trial S-1, Burn Time Z + One Minute, Camera Position CP-1.

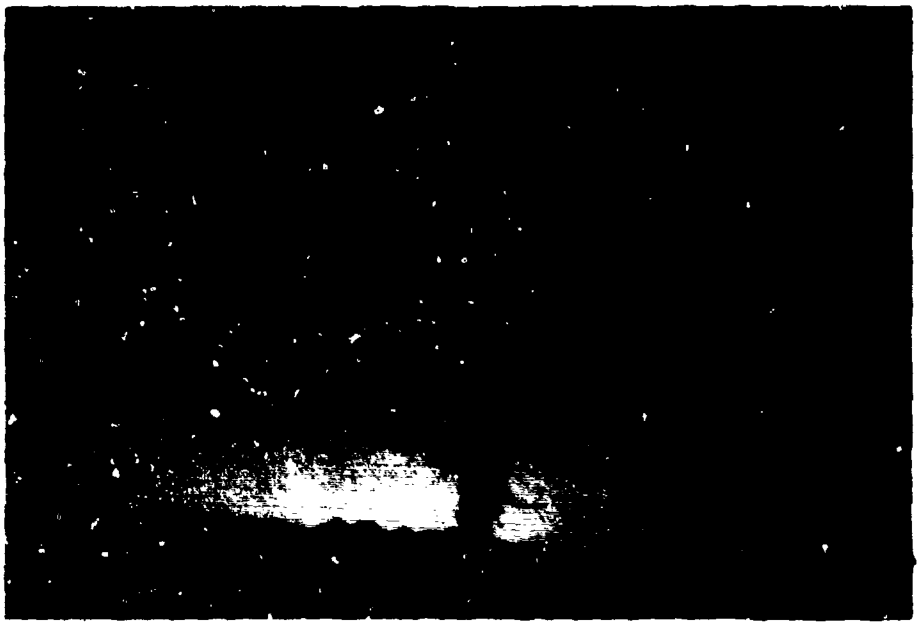


Figure I.39. Carbon Fiber Pool Fire Test, Trial S-1, Burn Time Z + Six Minutes, Camera Position CP-1.

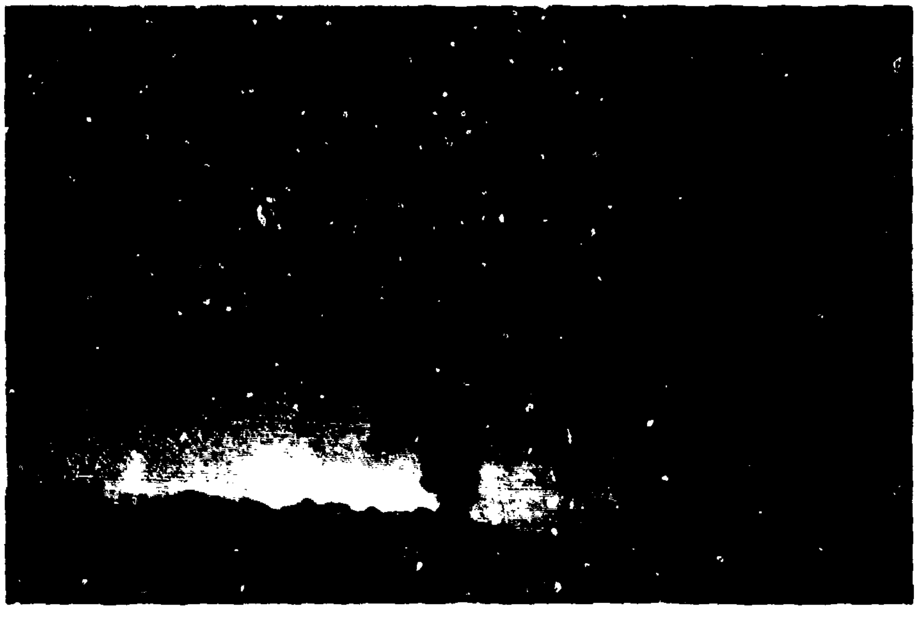


Figure I.40. Carbon Fiber Pool Fire Test, Trial S-1, Burn Time Z + Eleven Minutes, Camera Position CP-1.

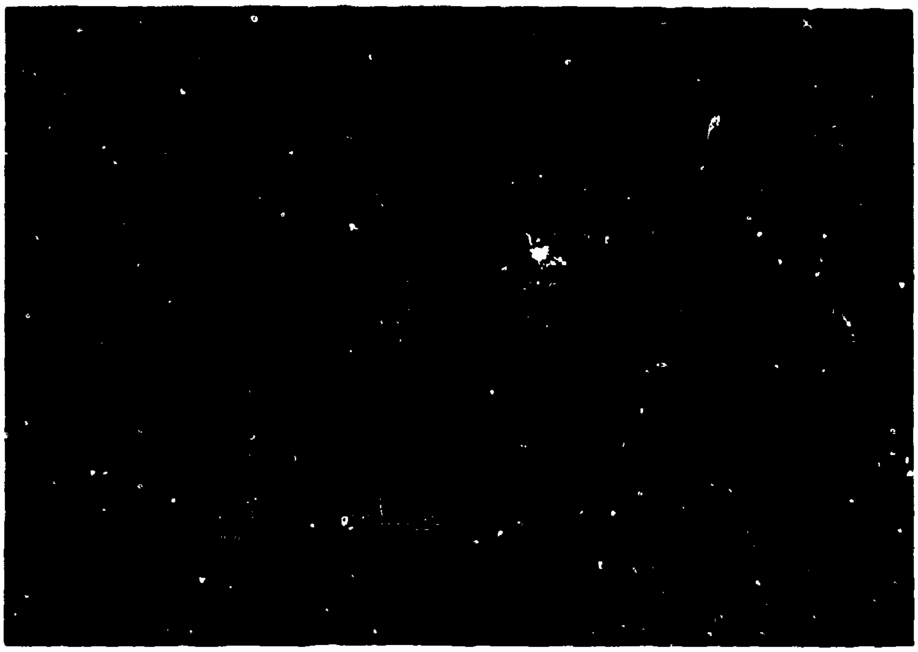


Figure I.41. Carbon Fiber Pool Fire Test, Trial S-1, Burn Time Z + Sixteen Minutes, Camera Position CP-1.

Figure I.42. Carbon Fiber Pool Fire Test, Trial S-1, Burn Time Z + Twenty-One Minutes, Camera Position CP-1.

TRIAL S-2 OF CARBON FIBER POOL FIRE TEST

Figures I.43 through I.47. The CP-4 camera was located 1524 m (5000 ft) upwind of the pool center. The camera was aimed southeast.

Figures I.48 through I.52. The CP-3 camera was located 1524 m (5000 ft) southwest of the pool center, on a line perpendicular to the grid center. The camera was aimed northeast.

Figure I.43. Carbon Fiber Pool Fire Test, Trial S-2, Burn Time Z + One Minute, Camera Position CP-4.

Figure I.44. Carbon Fiber Pool Fire Test, Trial S-2, Burn Time Z + Six Minutes, Camera Position CP-4.

Figure I.45. Carbon Fiber Pool Fire Test, Trial S-2, Burn Time Z + Eleven Minutes, Camera Position CP-4.

Figure I.46. Carbon Fiber Pool Fire Test, Trial S-2, Burn Time Z + Sixteen Minutes, Camera Position CP-4.

Figure I.47. Carbon Fiber Pool Fire Test, Trial S-2, Burn Time Z + Twenty-One Minutes, Camera Position CP-4.

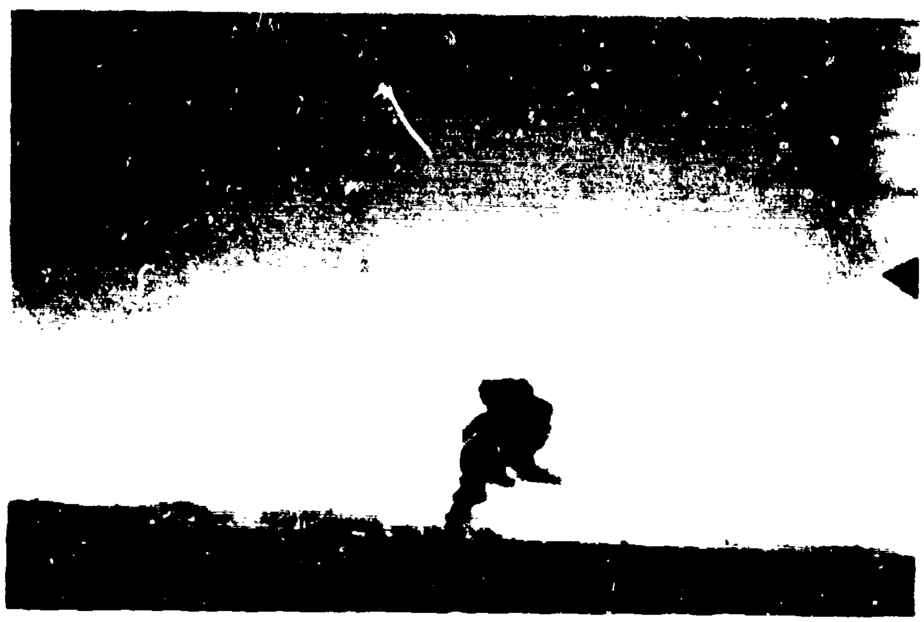


Figure I.48. Carbon Fiber Pool Fire Test, Trial S-2, Burn Time Z + One Minute, Camera Position CP-3.

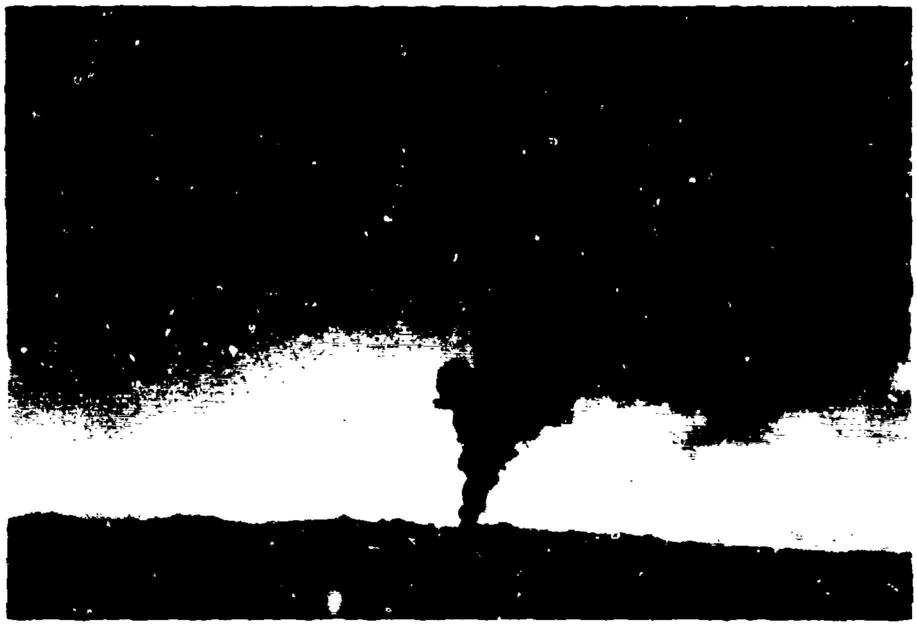


Figure I.49. Carbon Fiber Pool Fire Test, Trial S-2, Burn Time Z + Six Minutes, Camera Position CP-3.

Figure I.50. Carbon Fiber Pool Fire Test, Trial S-2, Burn Time Z + Eleven Minutes, Camera Position CP-3.

Figure I.51. Carbon Fiber Pool Fire Test, Trial S-2, Burn Time Z + Sixteen Minutes, Camera Position CP-3.

Figure I.52. Carbon Fiber Pool Fire Test, Trial S-2, Burn Time Z + Twenty-One Minutes, Camera Position CP-3.

APPENDIX J. METHODOLOGY STUDY FOR THE DEVELOPMENT OF A PASSIVE SAMPLER FOR FIRE-RELEASED CARBON FIBERS

Significant portions of DPG TR 78-314 (Reference 4) are reproduced as Appendix J to provide the reader with appropriate data from the methodology study. Original page numbers appear in the upper right corner of each page.

DUGWAY PROVING GROUND

TECHNICAL REPORT

DPG-TR-78-314

METHOGOLOGY STUDY FOR THE DEVELOPMENT OF A PASSIVE SAMPLER FOR FIRE-RELEASED CARBON FIBERS

BY

WILLIAM A. PETERSON

F. L. CARTER

JOHN H. WHITING

ABSTRACT

A passive carbon fiber sampler was developed for in-plume sampling (near the source) of fire-released carbon fibers. The sampler was designed to operate in a high temperature turbulent environment and sample a high flux of soot and fibers without overloading and loosing efficiency. Wind tunnels tests for the aerodynamics of the airflow through the sampling orifice were conducted for tunnel air speeds from 2.1 to 37.1 m/sec. The data from these tests indicated that airflow through the sampling orifice was near isokinetic when the tunnel air speed was <6 m/sec. When the tunnel air speed was >6 m/sec, a 16 percent over-isokinetic condition was observed. Also, wind tunnel tests of sampling efficiency were conducted with carbon fibers 5 mm long and 8 μm in diameter. For the efficiency tests, the wind tunnel air speeds were 3.0, 4.2, and 6.5 m/sec with the sampler positioned at 0, 30, and 45^0 from the direction of the tunnel airflow. The new sampler was compared to the standard DPG nylon mesh sampler and a recovery fraction of 0.94 was obtained from the efficiency test.

FOREWORD

This study was conducted for the National Aeronautics and Space Administration. Langley Research Center, Hampton, VA. US Army Dugway Proving Ground, UT was responsible for the conduct of the study and preparation of the report. The technical efforts of the personnel at the DPG Life Science Laboratory are greatly appreciated.

SECTION 1. SUMMARY (1)

1.1 BACKGROUND

An objective of the NASA/NAVY fire-released carbon fiber tests conducted at US Army Dugway Proving Ground (DPG), UT was to obtain an estimate of source strength. Ideally, source strength in-plume sampling should take place near the fire, but beyond the zone of carbon fiber oxidation. The environmental conditions in the preferred sampling area are:

a. In-plume temperatures can be several hundred degrees centigrade near the burning source, decreasing with distance until ambient temperature is reached.

b. The plume gases will be highly turbulent near the fire.

c. The plume will have a high flux of soot from burning fuel and composite material, clumps of carbon fibers, and single carbon fibers.

To function correctly under these conditions, a sampler design must meet certain criteria. The sampler must be designed to avoid overloading with soot and fibers, and to avoid loss of efficiency over time. The sampler should at least sample the net flux, in the direction of travel, over the sampling period. The sampling area should be small with respect to the filtering area.

The standard DPG nylon mesh sampler does not meet the criteria for in-plume source strength sampling, necessitating development of the passive carbon fiber sampler (CFS).

A CFS was calibrated by establishing its aerodynamics and efficiency. The Radiation Pad (Rad Pad) wind tunnel at DPG and the wind tunnel at Brigham Young University (BYU), Provo, UT were used to establish the CFS aerodynamics. The carbon fiber collecting efficiency was determined only in the DPG wind tunnel. The maximum capability of the DPG wind tunnel is approximately 6.5 m/sec. Therefore, BYU wind tunnel was used for wind speeds >6.5 m/sec, to a maximum of 35 m/sec.

1.2 OBJECTIVES

The objectives of this project were to design and develop a passive carbon fiber sampler to determine its operational efficiency and aerodynamic characteristics.

1.3 CONCLUSIONS

The passive CFS design meets the criteria for in-plume source strength sampling of carbon fibers.

b. The CFS calibrated in the DPG wind tunnel had a recovery fraction of 0.94 compared to the standard nylon mesh DPG sampler. This recovery fraction is for collection of 5-mm long carbon fibers, with sampler angles of 0, 30, and 45° and wind speeds <6.5 m/sec.

c. Airflow through the sampling tube appears to be isokinetic with respect to tunnel airflow up to about 6 m/sec. Beyond 6 m/sec, an over-isokinetic flow of about 16 percent is observed. It was assumed that the over-isokinetic flow of 16 percent will not significantly affect the sampling efficiency of the CFS.

d. To overcome the problem of soot and fibers overloading the sampler and degrading sampling efficiency, the ratio of the area of the wire mesh cloth filter to sampling area is 182:1 (or 80:1 for effective open area).

1.4 RECOMMENDATIONS

If a significantly large test program is required in the future, it is recommended that an additional methodology study be conducted to determine loss of fibers over a spectrum of fiber lengths. Experience indicates that sampling efficiency is dependent on the length of fibers being sampled (Reference 1).

SECTION 2. DETAILS OF STUDY (3)

2.1 SCOPE

The project consisted of designing and developing a passive carbon fiber sampler (CFS) for pool fire source strength tests. The aerodynamics and sampling efficiency were tested in wind tunnels.

2.2 PROCEDURES

Wind tunnel evaluation and theory have been presented in detail (Reference 2); no tunnel modifications were implemented.

2.2.1 Passive CFS

2.2.1.1 General Description of Passive Fire-Released CFS. The CFS consists of a cylindrical 16-gauge stainless steel outer casing containing a cylindrical wire mesh cloth (Figure 1). The outer casing is 25.4 cm in diameter and 50.8 cm long. An attached 15.3-cm cone section terminates on a sampling tube extending 7.6 cm into the casing. The internal attaching collar has an opening of 5.08 cm diameter. The wire mesh cylinder, which fits into the casing, is a 45.7-cm long, 20.32-cm diameter cylinder fabricated from 24-mesh stainless steel wire cloth. The cloth is a square weave purchased from Cambridge Wire Cloth Co., Cambridge, MD. The wire diameter is 0.356 mm with a 0.70-mm mesh opening between wires. The effective open area is 44.2 percent. One end of the filtering screen cylinder is fitted with a solid end plate to which a 5.1-cm diameter sampling tube is attached. The sampling tube extends forward 22.86 cm and 7.62 cm into the filter screen cylinder with the 7.6 cm length flared to a diameter of 7.62 cm. A wire cloth lid fits over the top opening of the screen. The screen section, with attached sampling tube, is placed in the outer casing and fastened in place by three set-screws imbedded in the attaching collar. A removable backplate baffle with a central opening of 7.62 cm fits into the back of the casing to complete the sampler.

The ratio of the sampling area of the sampling orifice to the filtering area of the wire mesh cloth is 1:182 (or 1:80 for effective open area).

The fibers are recovered from the wire mesh cloth filter by an air-washing technique. The screen and top of the CFS are placed in a cylindrical vacuum trap with a standard DPG nylon mesh sampler (Figure 2) in the bottom outlet of the air-wash. The fibers are dislodged from the screen by the vacuum in the air-wash and by blowing a gentle stream of air across the wire mesh cloth and sampling tube. After the air-washing is completed, the DPG nylon mesh sampler is recovered and assayed according to the appropriate DPG method for DPG nylon mesh samplers (Reference 1).

(4)

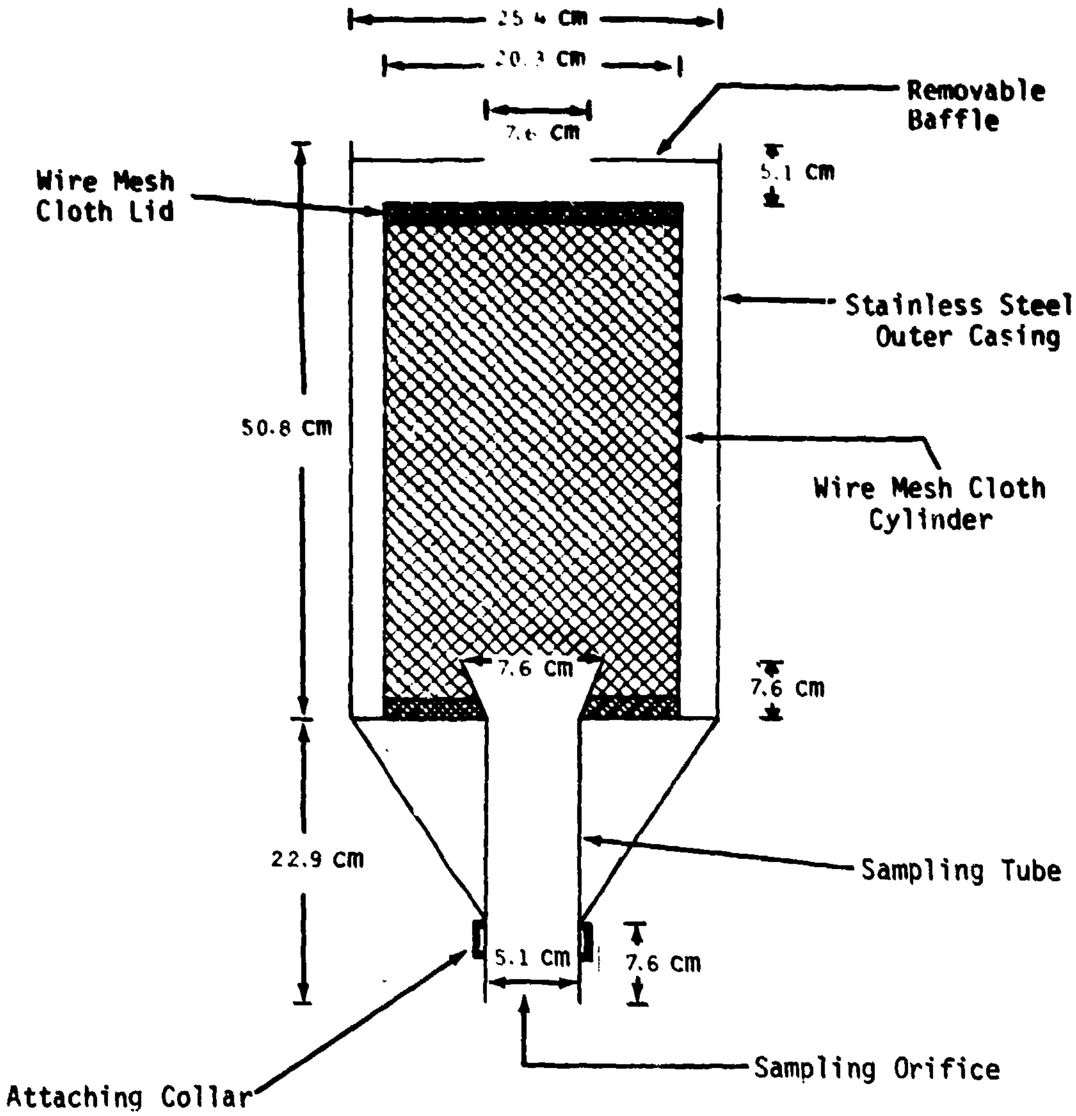


Figure 1. Design of Passive Carbon Fiber Sampler.

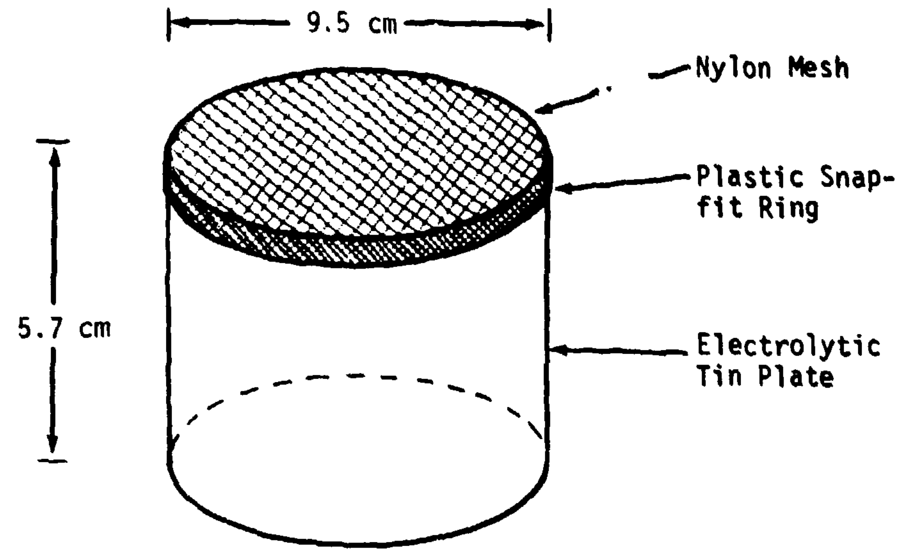


Figure 2. Standard DPG Nylon Mesh Sampler (Passive) Reference 1.

The sampler consists of a standard seamless cylinder of 0.5-mm electrolytic tin plate 5.7 cm high and 9.5 cm diameter. Nylon mesh consists of 17 monofilaments per 2.5 cm. For adhesion of fibers to the nylon mesh, the mesh is dipcoated in a mixture of lanolin, mineral oil, and toluene.

2.2.1.2. Method Used to Determine Sampler Efficiency. The physical model used to determine the sampling efficiency of the CFS versus the standard DPG nylon mesh sampler is shown in Figure 3.

The terms used for the physical model (Figure 3) are:

V_o = the wind speed at the test section of the wind tunnel.

C_o = the unperturbed concentration of the fibers immediately in front of the samplers.

V_m = the air speed on the upwind surface on the mesh of the standard DPG nylon mesh sampler.

V_s = the air speed immediately inside the sampling tube of the CFS.

A_m = the effective orifice area of the standard DPG nylon mesh sampler.

A_s = the orifice area of the CFS.

C_s = the concentration of the fibers in the CFS sampling orifice.

C_m = the concentration of fibers at the upwind surface of the mesh on the standard DPG nylon mesh sampler.

The numbers of fibers collected by the two samplers are given by:

$$N_m = \int A_m \; V_m \; C_m \; dt \text{ (standard DPG nylon mesh sampler)} \qquad (1)$$

$$N_s = \int A_s \; V_s \; C_s \; dt \text{ (CFS)} \qquad (2)$$

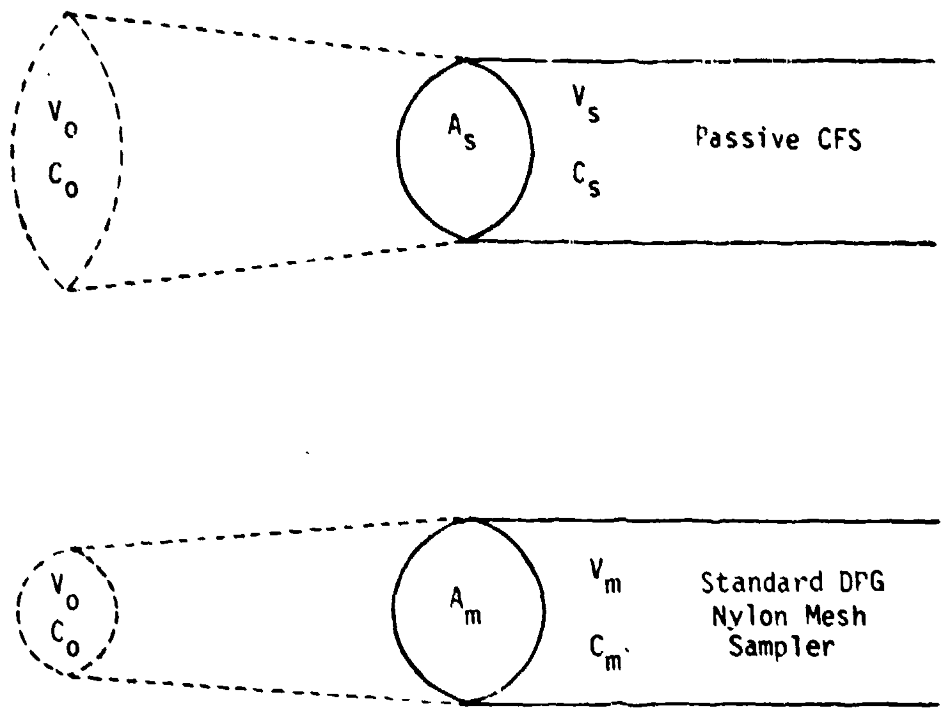
When wind speed and direction are constant, the Equations (1) and (2) can be written as:

$$N_m = A_m \; V_m \; E \int C_o \; dt \qquad (3)$$

$$N_s = A_s \; V_s \int C_s \; dt \qquad (4)$$

where E = efficiency $\left(\frac{C_m}{C_o}\right)$ of the standard DPG nylon mesh sampler compared to an isokinetic sampler.

(7)



NOTE: See text for explanation of terms.

Figure 3. Model for Determination of the Collection Efficiency of Passive CFS.

(8)

For our situation

$$A_s = \frac{A_m}{4} \cos \theta \tag{5}$$

θ = the angle between the axis of the passive CFS and wind direction. For the standard DPG nylon mesh sampler $\theta = 0$.

Dosage, defined by $D = \int C_o \, dt$, can be obtained by counting the number of fibers collected on the nylon mesh sampler $\left(N_m\right)$ and using the following relation

$$D = \frac{N_m}{A_m V_m E} . \tag{6}$$

It follows that if $A_m = 4 A_s / \cos \theta$

$$D = \frac{N_m \cos \theta}{4 A_s V_m E} \quad \text{or} \tag{7}$$

$$D = \frac{N_s}{A_s V_m E K} \tag{8}$$

$$\text{where } K = \frac{4 N_s}{N_m \cos \theta} \tag{9}$$

The objective of the calibration is to determine a value of K for different wind speeds and angles.

2.2.1.3 Sampler Calibration. The CFS calibration was divided into two parts. The primary purpose of the first part was to determine the aerodynamics of airflow through the CFS sampler tube. Once the aerodynamics were established, sampling efficiency was tested by subjecting the sampler to carbon fibers.

a. Aerodynamics. The first part of CFS calibration was conducted in the DPG and BYU wind tunnels with wind direction varying from normal to 45^0 and wind speeds 2 to 36 m/sec. A 0.32 cm (1/8-in) diameter stainless steel Pitot tube with an insertion length of 30.48 cm (12 in) was placed in the sampling tube with the tip of the Pitot tube 19.1 cm (7.5 in) from the sampler orifice. The Pitot tube was centered and aligned along the sampling tube center. Another Pitot tube in the wind tunnel

(9)

measured wind speeds near the sampler. Dynamic pressures measured by the Pitot tubes were recorded with a MKS Baratron. The Baratron is capable of recording changes of 0.0001 mm Hg dynamic pressure. The dynamic pressure (q) is given by

$$q = \left(\frac{V}{20.598}\right)^2 \left(\frac{P}{T + 460}\right) \qquad (10)$$

where

q = dynamic pressure (mm Hg)

V = tunnel wind speed (m/sec)

P = barometric pressure (millibars)

T = air temperature (°F)

The data obtained from this test are prepared in Appendix Table B.1 and Figure 4. Appendix Table B.1 and Figure 4 indicates an isokinetic state up to about 6 m/sec and an above isokinetic airflow of 16 percent beyond 6 m/sec.

b. Efficiency. To determine sampler efficiency, the samplers were placed in DPG wind tunnel as shown in Figure 5. The sampling array in Figure 5 was used for 27 trials. Tunnel wind speeds were varied at 3.0, 4.2 and 6.5 m/sec for CFS angles of 0, 30, and 45^0. Carbon fibers 5.0 mm long and 8 μm in diameter were disseminated. An air blower (manufacturer's trade name: Skil) was used to disseminate the carbon fibers against the airstream to disperse the fibers across the test section of the wind tunnel. The results of these trials are present in Appendix Table B.2. The value of K is determined from the physical model and using data reduction for the average of the standard DPG nylon mesh samplers.

The maximum capability of the wind tunnel at DPG was 6.5 m/sec wind speed. The wind tunnel at BYU would not lend itself to sampler efficiency measurements with carbon fibers; consequently, it could not be used for this test.

2.2.1.4 Statistical Analysis of Wind Tunnel Data.

a. Calibration of the Wind Tunnel. Prior to calibrating any sampling devices, a test was performed to determine the uniformity of fiber concentrations for the sampling array in the test section of the wind tunnel. The test section of the DPG wind tunnel was arrayed (Figure 5) with standard DPG nylon mesh samplers (Figure 2). Three wind speeds (3.0, 4.2, and 6.5 m/sec) and three repetitions of each sampler position-wind speed treatment combinations were used. Because sampler positions were fixed, this was a split plot experiment with the sampler positions (whole plot) in "stripes" throughout the experiment. the "whole plots" were then split by the three wind speeds (sub-plots) (Reference 3).

(10)

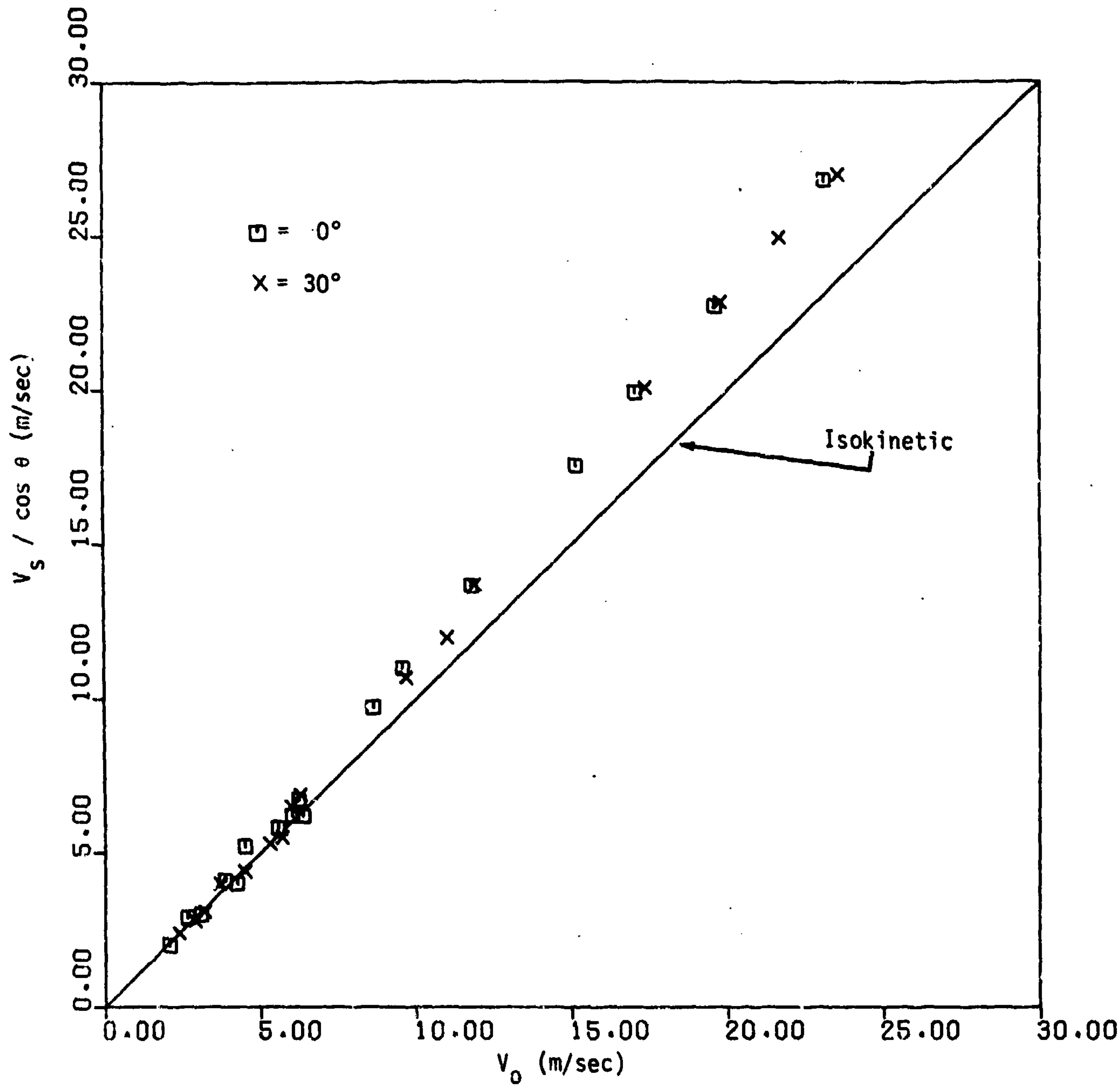


Figure 4. Sampler Tube Wind Speed (V_s) Divided by cos θ versus Wind Tunnel Speed (V_o).

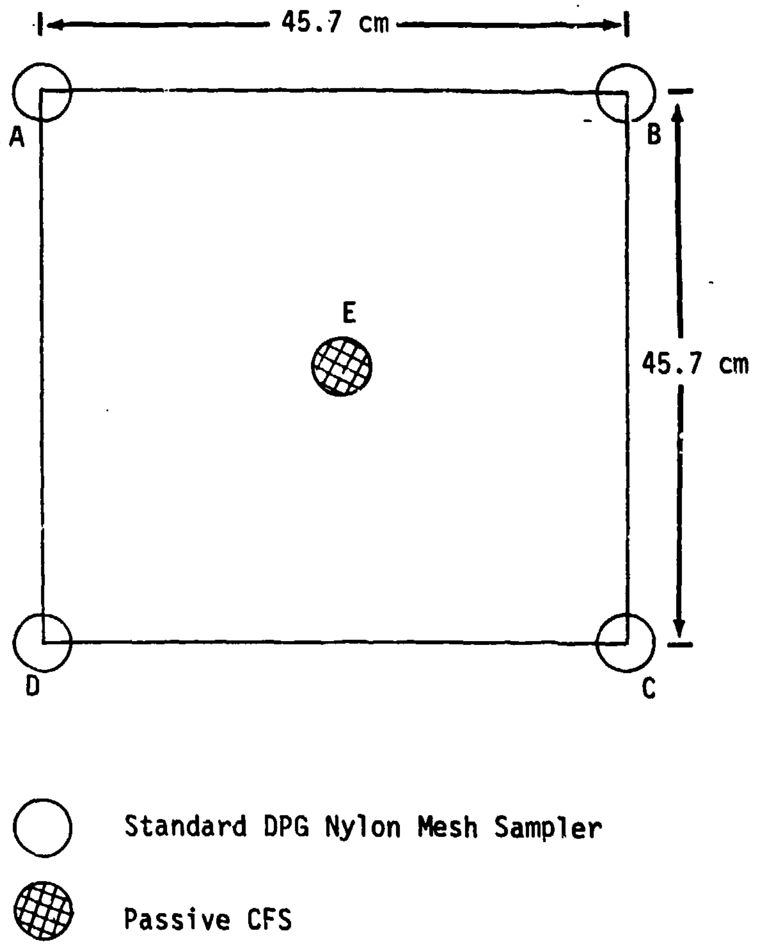


Figure 5. Sampling Array for Determining Sampling Efficiency of Two Different Passive Samplers, Test Section of Wind Tunnel at DPG.

Data collected from this experiment are shown in Appendix Table B.3. Following each wind tunnel test, the samplers were identified and assayed according to the appropriate DPG SOP for carbon fiber assessment.

An analysis of variance was performed to identify major sources of significant variation on total counts recovered from each sampler (Table 1). A study of assay variability was not an objective of this experiment; the assumption was made that assay variability was small in comparison to those sources of variation that were taken under consideration. Source strength variation is inherent in the trial variation and will be part of the Repetition/PxS effect in the analysis and/or Replication effect when it is present. The important feature of the analysis of variance is that these sources of variation are separated from those attributes that are of particular interest.

Table 1. Analysis of Variance of Standard DPG Nylon Mesh Sampler Recoveries (Counts per Sampler) for Wind Tunnel Calibration Experiment.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F_{comp}	F_{tab}
Position (P)	4	220,852	55,213	4.53	3.84
Speed (S)	2	121,792	60,896	5.00	4.46
PxS	8	97,498	12,187	<1.00	Not Significant
Repetition/PxS	30	649,054	21,635		
Total	44	1,089,196			

In the last two columns of Table 1, F_{comp} exceeds F_{tab}, therefore a statistically significant difference among position and wind speed means was observed (5 percent significance level).

As shown in Table 2, the lower left sampling position average was statistically different from the upper right sampling position average recovery. Although the lower right sampling position average recovery was not statistically different from the other average recoveries, it was numerically lower than the upper three positions, showing a bias to lower average recoveries in the lower sampler positions.

Table 2. Average Sampler Recovery, by Position (as shown in Figure 5), for Wind Tunnel Calibration.

698.3		737.1
	680.7	
543.9		626.1

Average recovery at the 3.0 m/sec wind speed was statistically lower than the average recoveries observed at either the 4.2 m/sec or 6.5 m/sec wind speeds. The average recoveries are shown in Table 3, by wind speed.

Table 3. Average Sampler Recovery, by Wind Speed, for Wind Tunnel Calibration.

Wind Speed (m/sec)	3.0	4.2	6.5
Average Recovery (Count/Sampler)	585.5	670.7	710.1

b. Calibration of the CFS. Because of the difference in size between the CFS and the standard DPG nylon mesh samplers, the CFS was placed in the center of the five-sampler array (Figure 4) and remained in that position throughout the experiment. Physical limitations precluded randomizing the CFS position over the five-sampler array in the wind tunnel. In a statistical sense, position and sampler were confounded. By utilizing the wind tunnel calibration data reported above, it could be assumed that any statistical differences involving the CFS could be attributed to the CFS rather than a position difference.

The standard DPG nylon mesh sampler was as described above and shown in Figure 2. The CFS was described in paragraph 2.2.1 and illustrated in Figure 1.

The wind speeds (3.0, 4.2, and 6.5 m/sec) were the same as used to calibrate the wind tunnel. The CFS was oriented at three angles to the wind (0°, 30°, and 45°). The CFS data were treated with a cosine correction factor. Angle effects were then considered to be replication effects. The collection area of the standard DPG nylon mesh sampler is four times that of the CFS and the CFS data were adjusted accordingly.

As with the wind tunnel calibration, this was a split-plot experiment where sampler positions (whole plot) were in strips; the whole plots were then split into sub-plots by the three wind speeds. Three repetitions of each position-wind speed treatment were performed and three replicates of the experiment were conducted.

Data collected from this experiment are shown in Appendix Table B.3. After each wind tunnel test, the samplers were identified and assayed according to the appropriate DPG SOP for carbon fiber assessment.

An analysis of variance (Table 4) was performed on total sampler recoveries, with the adjustments to the data as previously mentioned.

Table 4. Analysis of Variance of Sampler Recoveries (Counts per Sampler) for CFS Calibration Experiment.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F_{comp}	F_{tab}
Replication (R)	2	1,566,010	783,005	144.58[a]	4.46
Position (P)	4	226,865	56,716	10.47[a]	3.84
RxP	8	43,324	5,416	0.25	2.59
Speed (S)	2	472,707	236,353	11.73[a]	3.63
PxS	8	170,973	21,372	1.06	2.59
RxS	4	399,912	99,978	4.96[a]	3.01
RxPxS	16	322,502	20,156	0.92	1.80
Repetition/RxPxS	90	1,970,654	21,896		
Total	134	5,172,947			

[a]The probability that the observed difference is due to chance alone is <0.01.

In dealing with an analysis of variance, interaction terms must be dealt with first because certain significant interactions preclude discussion of main effects. In the analysis presented in Table 4, the only statistically significant interaction was replicate by wind speed. The interaction is the result of degree, i.e., the average replicate differences for each wind speed are of a different magnitude and there is one slight crossover. For this reason, the interaction was ignored so that inferences concerning main effects could be made. The most significant contribution to the overall analysis was that the replicate by wind speed variation and the replication main effect variation were isolated (and identified) from the total variation.

Position/sampler average recoveries shown in Table 5 are arrayed in the positions shown in Figure 5. The statistical analysis (Table 4) indicates that the lower right position (position C) average recovery is statistically lower than the center position (CFS) which is statistically lower than average recoveries observed at the other three positions (positions A, B, and D). It was anticipated that the border samplers (all DPG standard nylon mesh samplers) would maintain the average recovery order (i.e., lower left position with statistically lower recovery than the upper right). However, this was not the case. In an attempt to resolve this situation, the statistically equal average recoveries were again averaged to form the ratio with the CFS sampler (see paragraph 2.3). The reason for the significantly lower recovery in the lower right position and the apparent reversal from the calibration phase is not known.

Table 5. Average Position Sampler Recovery, by Position (as shown in Figure 5), for CFS Calibration.

690.2		680.6
	644.3	
693.9		584.6

As observed in the wind tunnel calibration phase, the average recovery at the 3.0-m/sec wind speed was statistically lower than the averages observed at the 4.2- and 6.5-m/sec wind speeds. The average recoveries are shown, by wind speed, in Table 6.

Table 6. Average Sampler (CFS and Standard DPG Nylon Mesh) Recovery, by Wind Speed.

Wind Speed (m/sec)	3.0	4.2	6.5
Average Recovery (Count/Sampler)	575.6	691.8	708.8

To resolve the problems caused by the reversal of the significantly low recovery from the lower left position to the lower right position between the tunnel calibration phase and the CFS calibration phase, an analysis was performed with a reduced set of CFS data. The data set was reduced by deleting the first replicate (because it made the greatest contribution to the significant replicate mean square), the 3.0 m/sec wind speed (for the above reason), and sampling positions C and D (because they contributed to significance in the wind tunnel calibration and CFS calibration, respectively). Because the data components contrib-

uting the greatest amount to the significant variation (in each instance) were deleted, it was anticipated that statistical differences would not be observed. However, the power of the analysis was also reduced.

A significant replication effect is still present, however all other significant effects have vanished, either because of the correct deletion of data or because of the weakened analysis. The averages by sampling position (Figure 5) are shown in Table 7.

Table 7. Average Sampler Recovery, by Position (as shown in Figure 5), for the Reduced Data Set of the CFS Calibration Experiment.

844.42		789.00
	780.75	

The analysis of variance for the CFS reduced data set is shown in Table 8.

Table 8. Analysis of Variance of Sampler Recoveries (Counts per Sampler) for the Reduced Data Set of the CFS Calibration Experiment.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F_{comp}	F_{tab}
Replication (R)	1	188,645	188,645	37.37[a]	18.5
Position (P)	2	28,770	14,385	2.85	19.0
RxP	2	10,097	5,048	<1.00	19.0
Speed (S)	1	23,922	23,922	1.29	18.5
PxS	2	21,486	10,743	6.20	18.5
RxS	1	114,695	114,695	<1.00	19.0
RxPxS	2	37,012	18,506	<1.00	3.40
Repetition/RxPxS	24	795,105	33,129		
Total	35	1,219,732			

[a]The probability that the observed difference is due to chance alone is <0.05.

2.3 CFS RECOVERY FRACTION (17)

An average recovery fraction for the CFS was determined from data in Table 5. As previously stated, the lower right position (position C) average recovery was statistically lower than the average recovery for the other border samplers (positions A, B, and D). Therefore, the average recovery of position C was not used for determining a CFS recovery fraction.

The recovery fraction for the calibration, 0.94 for tunnel wind speeds of 3.0, 4.2, and 6.5 m/sec., is the ratio of the CFS average to the average of the border nylon mesh sampler position (A, B, and D, Table 5) averages. This produces a consistent result with equation 9.

From the data in Table 7 which lists the average sampler recovery (by position) for the reduced data set, a CFS recovery fraction of 0.96 was obtained.

REFERENCES FOR APPENDIX J (A-1)

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TEST DATA (TABULATED CALIBRATION DATA)

Table B.1. Aerodynamic Data of Wind Tunnel Air Speeds (V_o) Versus Sampler Tube Air Speeds (V_s) at Sampler Angles 0, 30, and 45°.

Sampler Angle to Wind Direction 0°			Sampler Angle to Wind Direction 30°			Sampler Angle to Wind Direction Between 45 - 50°		
Tunnel Air Speed (V_o) m/sec	Sampler Tube Air Speed (V_s) m/sec	V_s/V_o	Tunnel Air Speed (V_o) m/sec	Sampler Tube Air Speed (V_s) m/sec	V_s/V_o	Tunnel Air Speed (V_o) m/sec	Sampler Tube Air Speed (V_s) m/sec	V_s/V_o
2.1	2.0	0.95	2.4	2.1	0.88	2.4	1.5	0.64
2.7	2.9	1.07	2.9	2.4	0.83	2.9	1.7	0.60
3.1	3.0	0.97	3.2	2.7	0.84	3.3	2.1	0.64
3.9	4.1	1.05	3.7	3.5	0.94	4.1	2.7	0.66
4.2	4.0	0.95	4.5	3.8	0.84	4.5	2.5	0.56
4.8	5.2	1.08	5.3	4.6	0.88	5.0	3.1	0.62
5.6	5.8	1.04	5.7	4.8	0.84	5.7	3.8	0.67
6.0	6.2	1.03	6.0	5.6	0.93	6.1	4.0	0.66
6.4	6.2	0.97	6.3	6.0	0.95			
6.2	6.7	1.08	9.7	9.3	0.96			
8.6	9.7	1.13	11.0	10.4	0.95			
9.6	11.0	1.14	11.9	11.9	1.00			
11.8	13.6	1.15	17.4	17.4	1.00			
15.1	17.6	1.16	19.8	19.8	1.00			
17.0	20.0	1.17	21.7	21.7	1.00			
19.6	22.8	1.16	23.6	23.4	0.99			
23.1	26.8	1.16	32.6	32.6	1.00			
32.0	37.1	1.16	35.6	36.3	1.02			

Test in excess of 6.1 m/sec were conducted at BYU. Physical dimensions of the tunnel precluded angles beyond 30°.

(B-2)

Table B.2. Total Counts of Carbon Fibers Recovered During Wind Tunnel Calibration of CFS.

REPLICATION	WIND SPEED (m/sec)	REPETITION	WIND TUNNEL POSITION				
			A	B	C	D	E
1	3.0	1	384	443	507	360	500
		2	407	373	311	355	408
		3	586	629	520	381	468
	4.2	1	600	640	541	614	552
		2	543	604	436	414	464
		3	483	527	416	437	608
	6.5	1	361	476	497	375	372
		2	1002	567	775	398	580
		3	613	801	558	504	512
2	3.0	1	675	720	681	671	679
		2	864	706	849	770	615
		3	702	389	956	597	656
	4.2	1	737	803	993	749	938
		2	822	786	702	447	711
		3	652	683	840	567	735
	6.5	1	591	894	674	531	716
		2	420	423	399	508	301
		3	982	1000	867	948	988
3	3.0	1	467	433	520	427	538
		2	549	572	821	743	634
		3	671	623	766	535	442
	4.2	1	935	938	817	759	747
		2	907	916	995	680	640
		3	731	655	1044	636	685
	6.5	1	793	833	766	864	978
		2	978	1127	822	763	968
		3	920	1075	662	752	962

Table B.3. Total Counts of Carbon Fibers Recovered During Wind Tunnel Calibration Analysis

WIND SPEED (m/sec)	REPETITION	WIND TUNNEL POSITION				
		A	B	C	D	E
3.0	1	550	483	519	403	670
	2	772	527	447	618	639
	3	760	646	549	619	530
4.2	1	667	539	457	590	584
	2	797	777	647	760	683
	3	734	734	653	707	731
6.5	1	512	748	289	381	521
	2	943	885	748	682	963
	3	899	946	505	875	755

APPENDIX K. TEMPERATURE DATA FOR NASA CARBON FIBER POOL FIRE TESTS

1. Thermocouples were connected to a reference junction which did not allow recording temperatures less than 76°C (169°F). Instrument saturation limited recording temperatures greater than 1415°C (2580°F).

2. Specimen numbers shown on figures for thermocouple locations can be cross referenced to Appendix L for discriptions and dimensions.

Table K.1. Thermocouple Locations for NASA Carbon Fiber Pool Fire, Trial D-1, 26 October 1979.

Thermocouple Number	Specimen Number	Thermocouple Location
1	1-1	In speed brake
2	Ambient	In sleeve near speed brake
3	1-2	Inside hat stiffener
4	Ambient	In sleeve near thermocouple number 3
5	1-10	Under sample
6	Ambient	In sleeve near thermocouple number 5
7[a]	Ambient	On guy wire NW of pool
8	1-12 and 1-13	Between specimans
9	Ambient	In sleeve near thermocouple number 8

[a]No temperature was recorded; thermocouple did not exceed 76°C.
NOTE: Thermocouple and specimen locations are shown in Figure K.1.

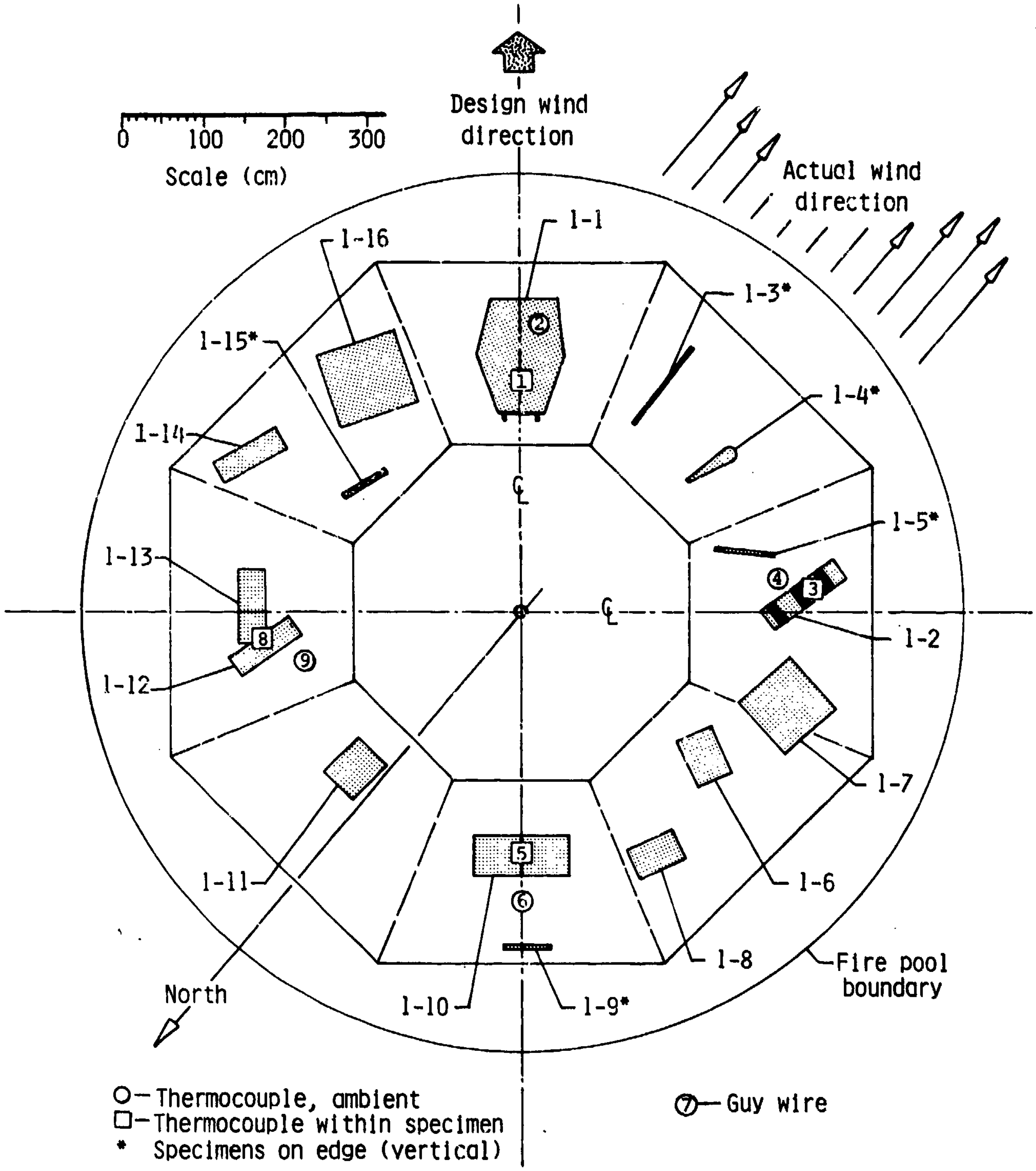


Figure K.1. Thermocouple Location for Pool Fire D-1, 26 October 1979.

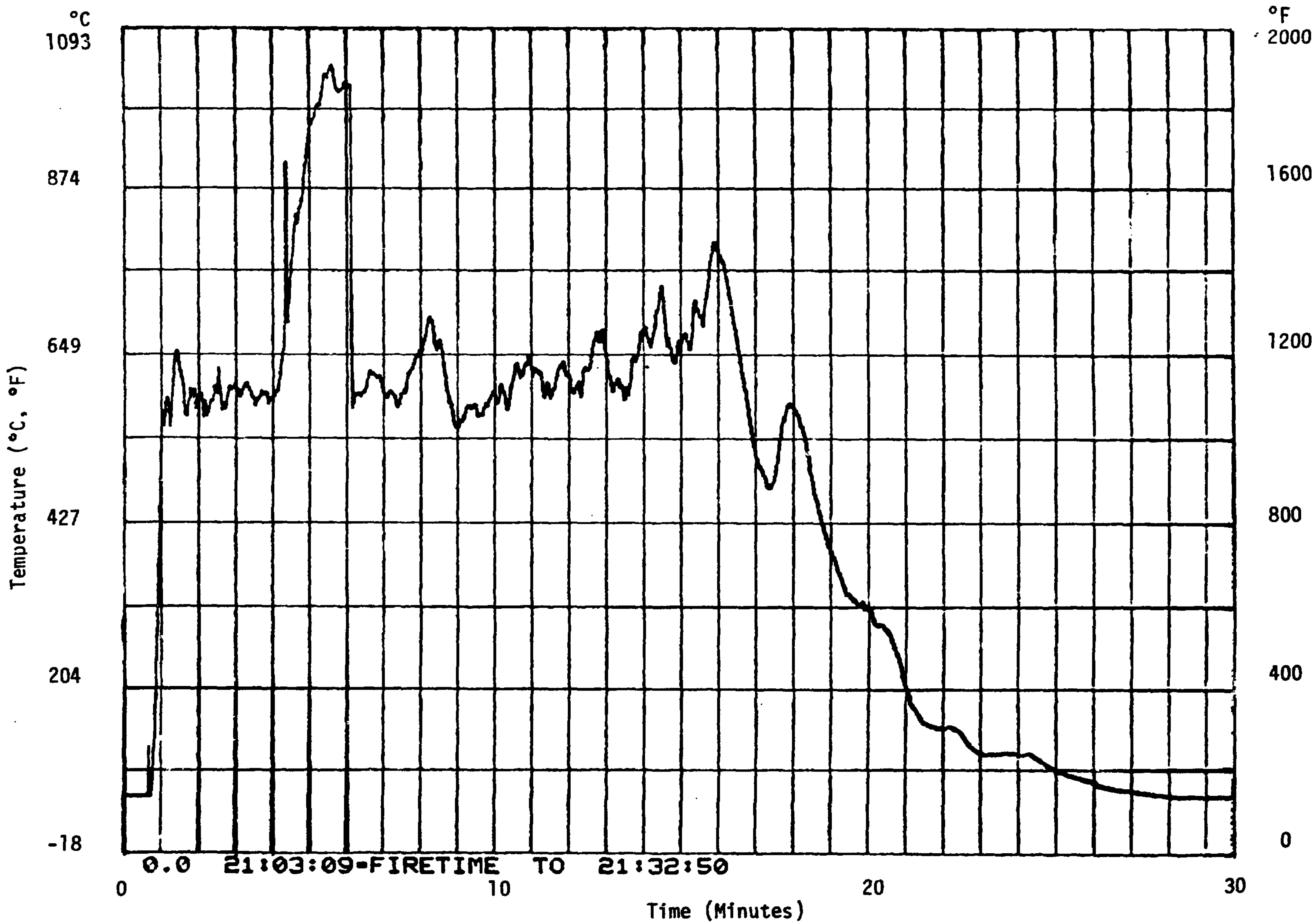


Figure K.2. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-1, 26 October 1979, Thermocouple Number 1.

Figure K.3. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-1, 26 October 1979, Thermocouple Number 2.

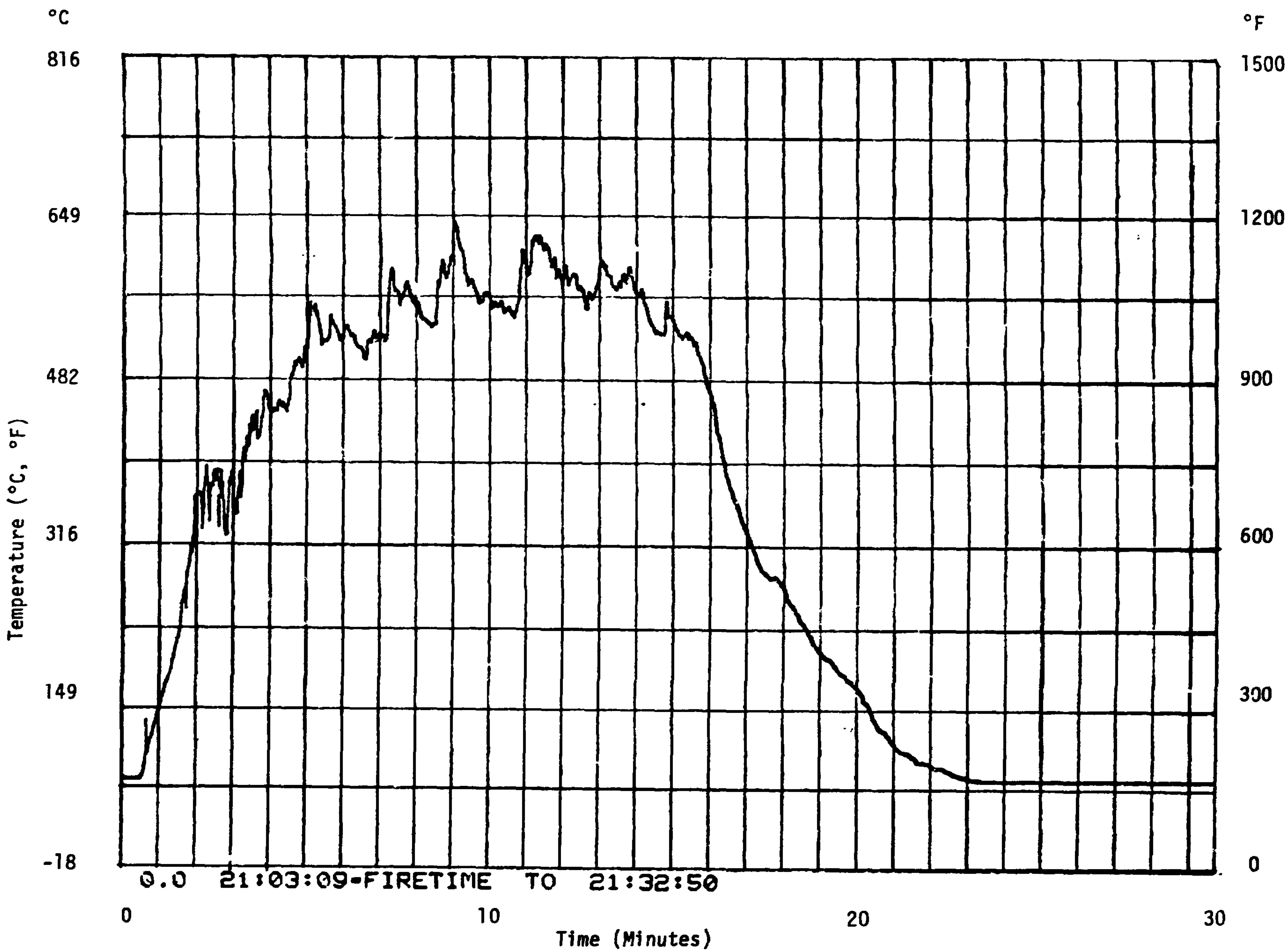


Figure K.4. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-1, 26 October 1979, Thermocouple Number 3.

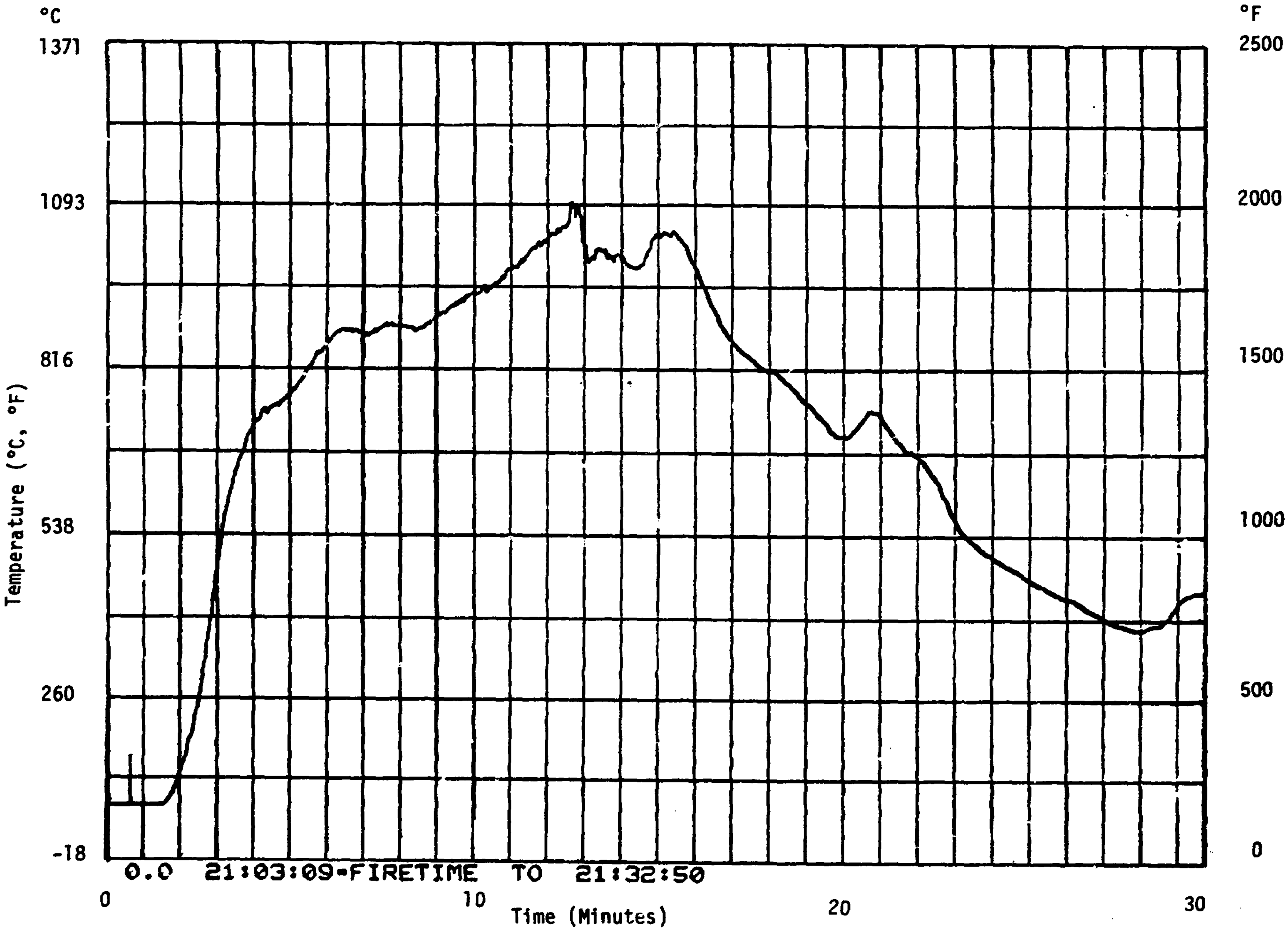


Figure K.5. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-1, 26 October 1979, Thermocouple Number 4.

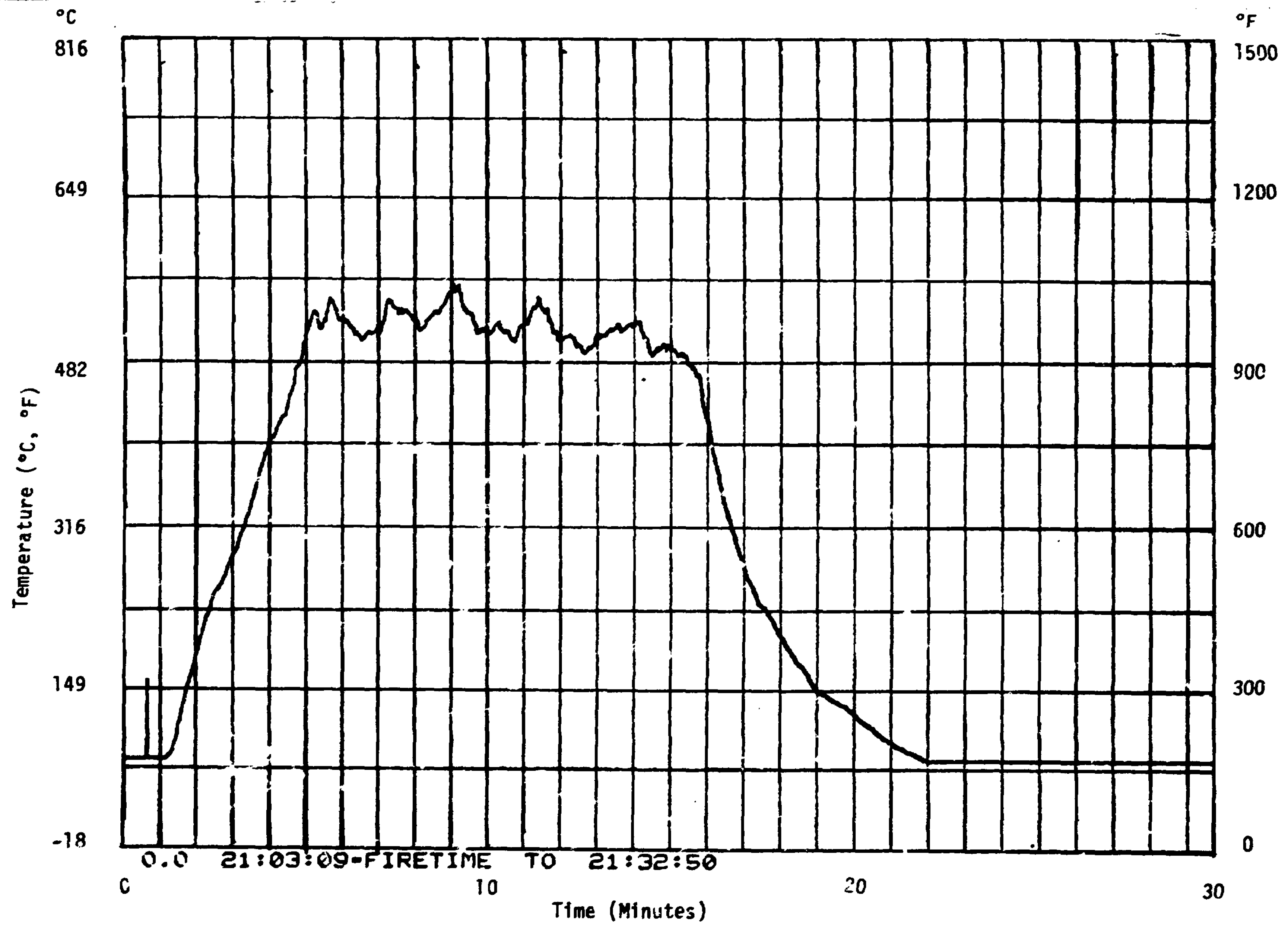


Figure K.6. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-1, 26 October 1979, Thermocouple Number 5.

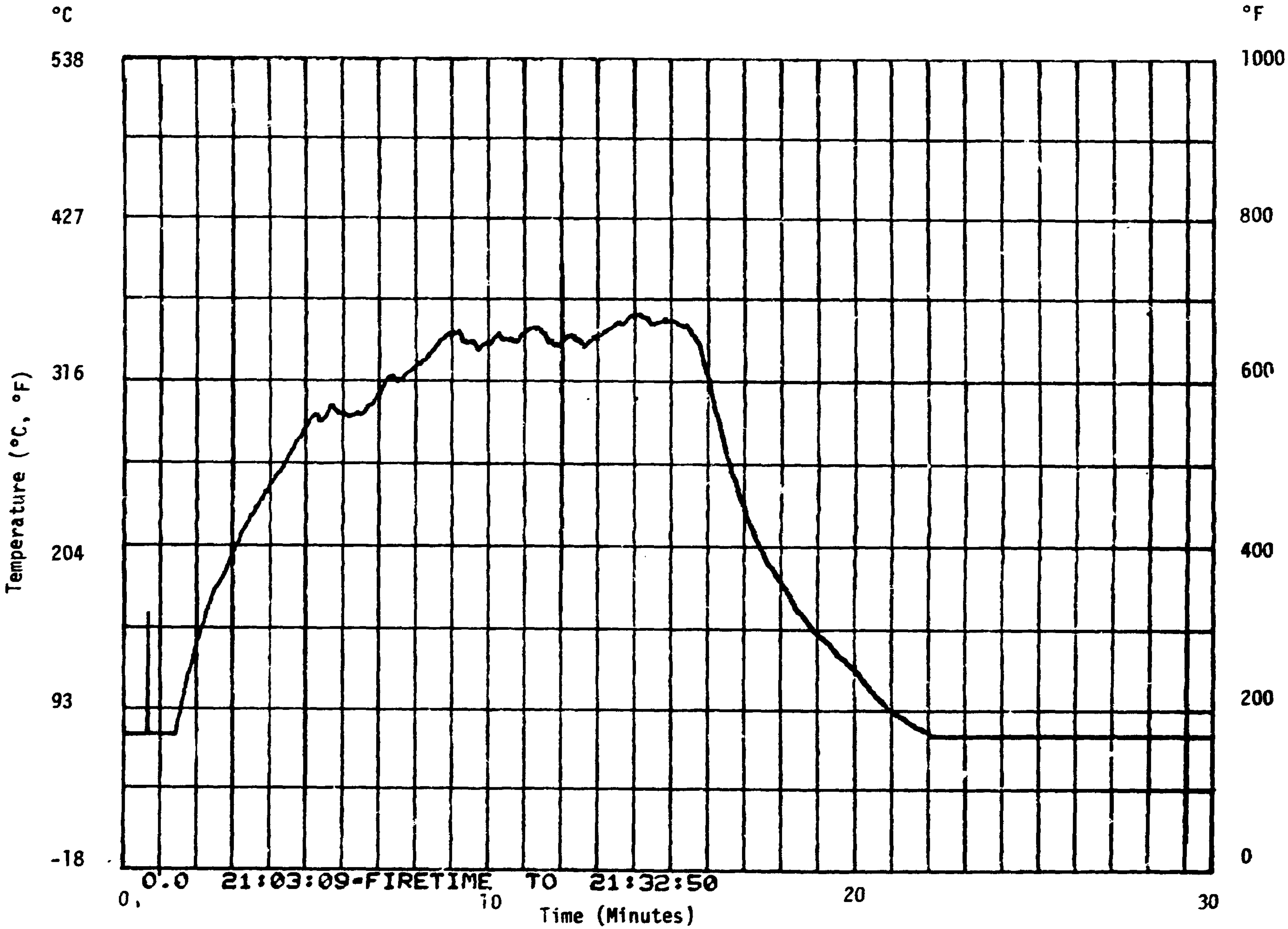


Figure K.7. Temperature Measurements for NASA Carbon Fiber Pool Trial D-1, 26 October 1979, Thermocouple Number 6.

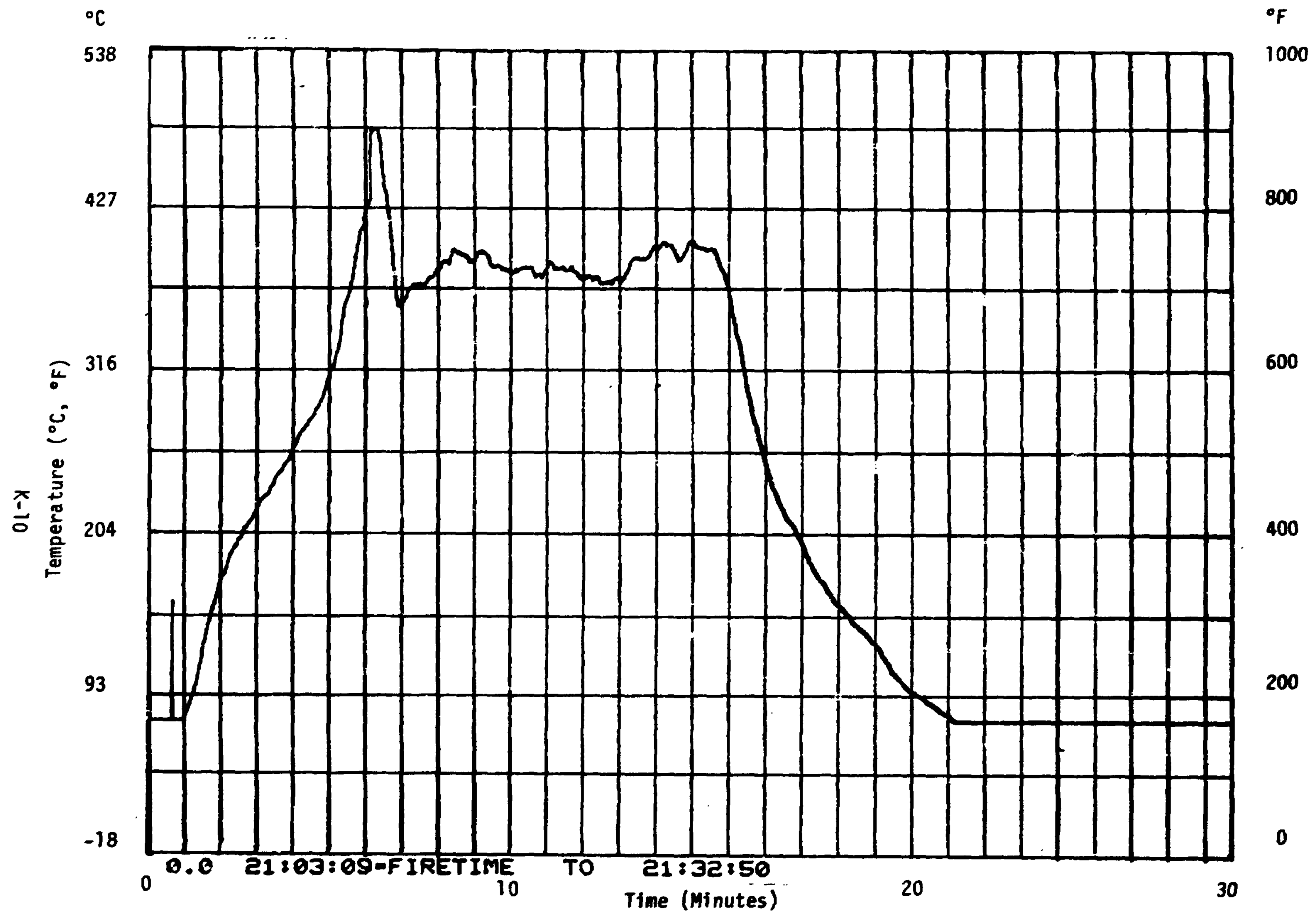


Figure K.8. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-1, 26 October 1979, Thermocouple Number 8.

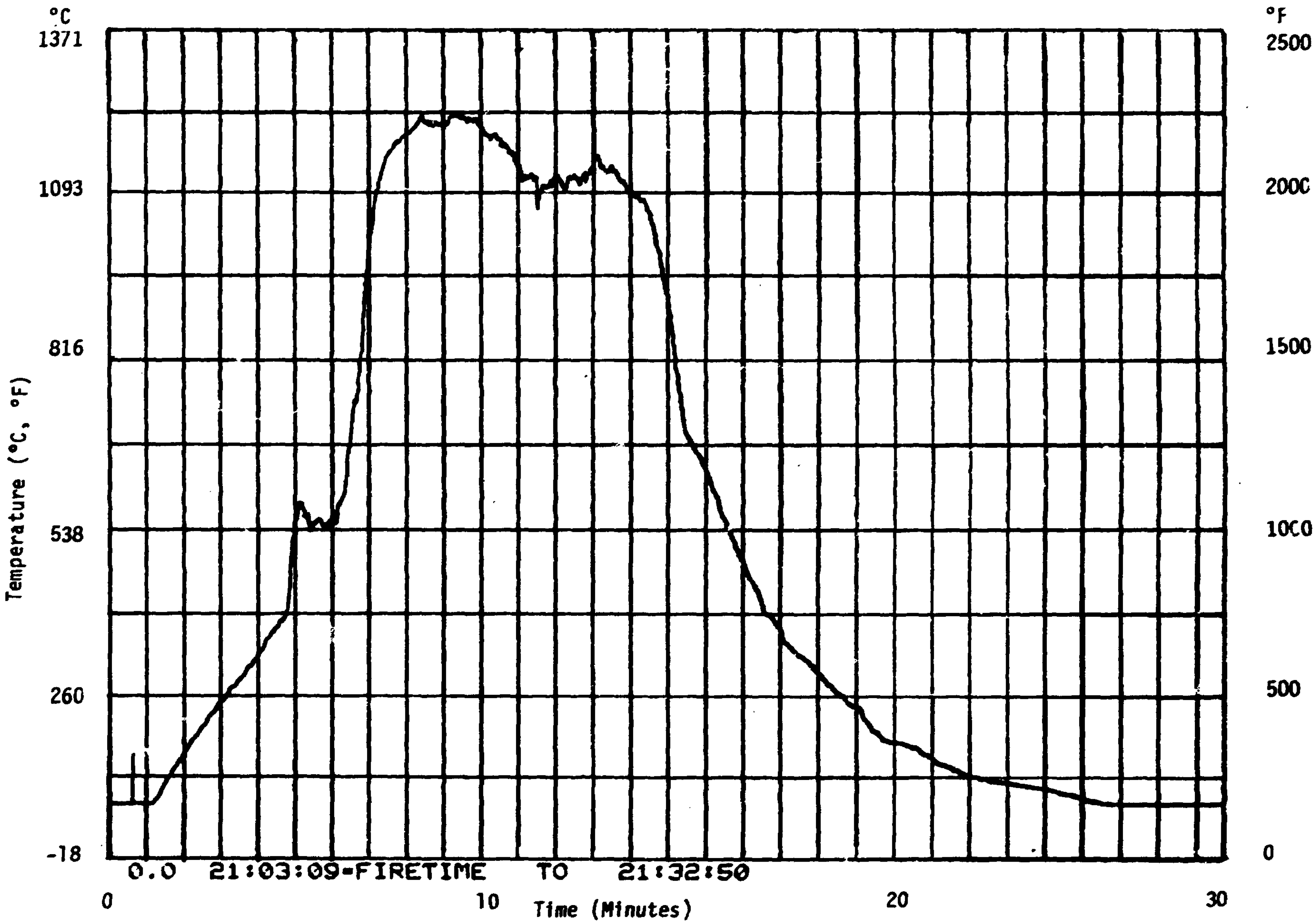


Figure K.9. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-1, 26 October 1979, Thermocouple Number 9.

Table K.2. Thermocouple Locations for NASA Carbon Fiber Pool Fire, Trial D-2, 31 October 1979.

Thermocouple Number	Specimen Number	Thermocouple Location
1	2-20	Inside hat stiffener
2	Ambient	In sleeve near specimen
3	2-10	Inside hat stiffener
4	Ambient	In sleeve near specimen
5	2-13	Under specimen
6	Ambient	In sleeve near specimen
7	Ambient	On guy wire NW of pool
8	Ambient	In sleeve near specimen
9	2-12	Under specimen

NOTE: Thermocouple and specimen locations are shown in Figure K.10.

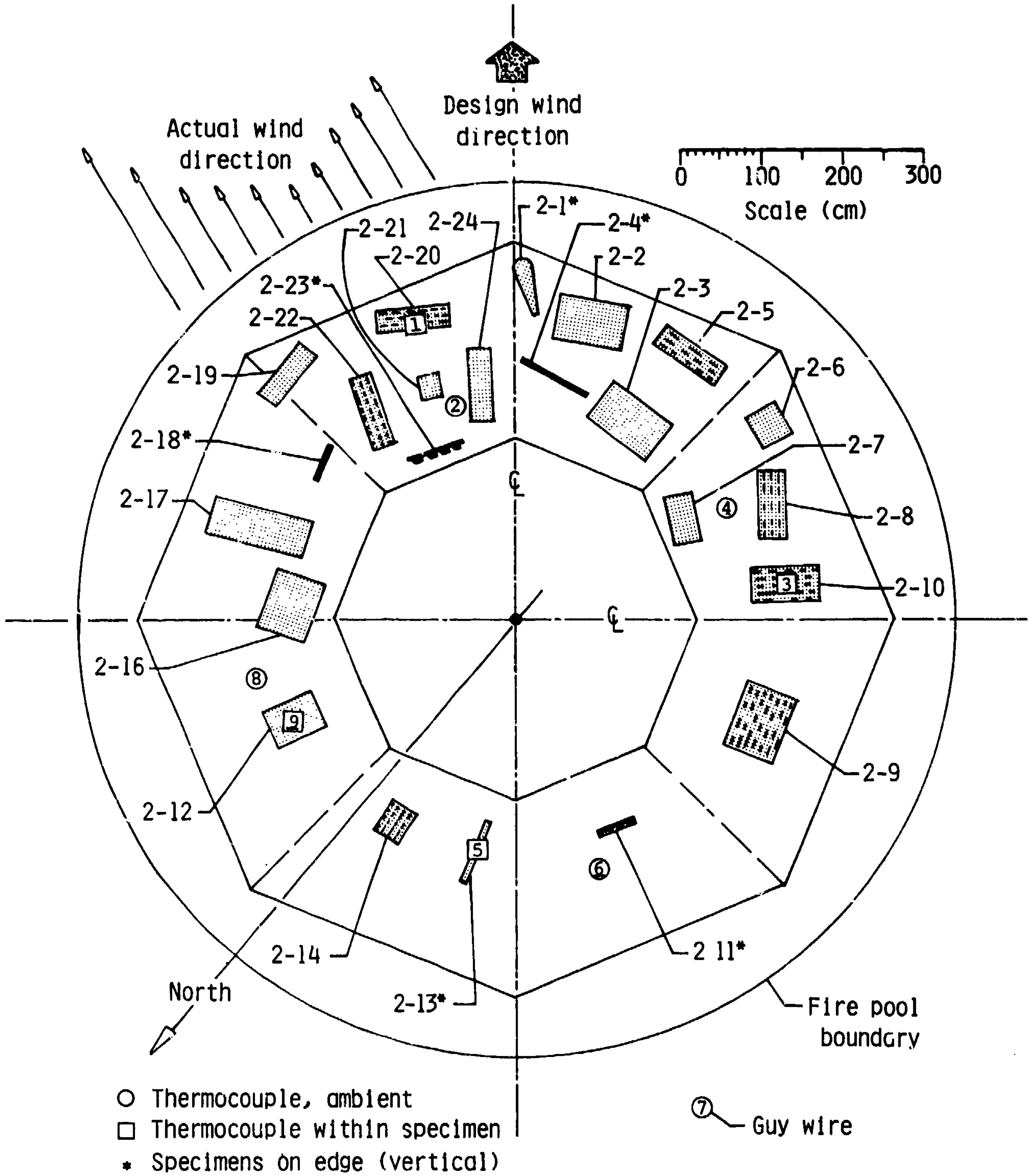


Figure K.10. Thermocouple Location for Pool Fire D-2, 31 October 1979.

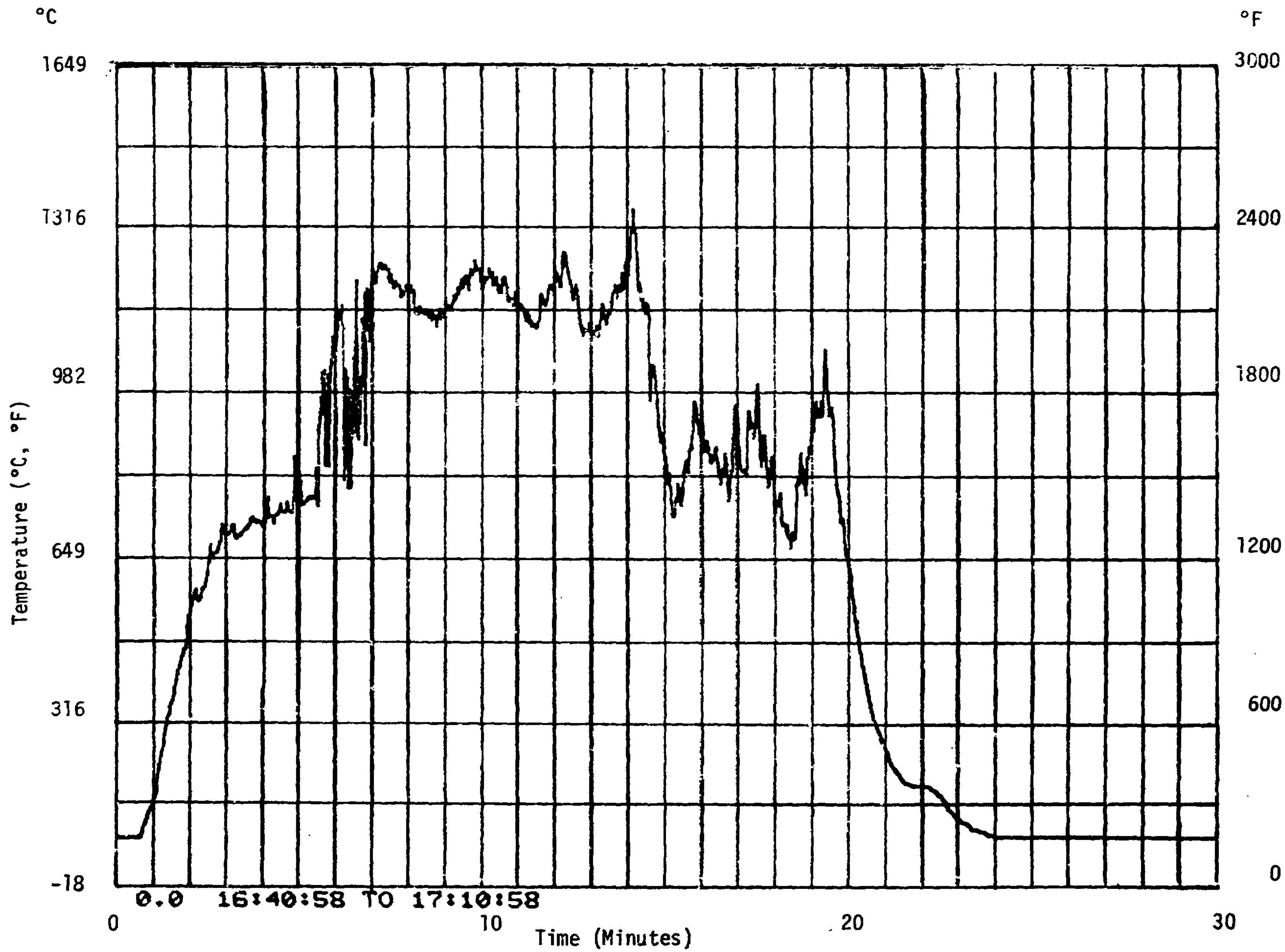


Figure K.11. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-2, 31 October 1979, Thermocouple Number 1.

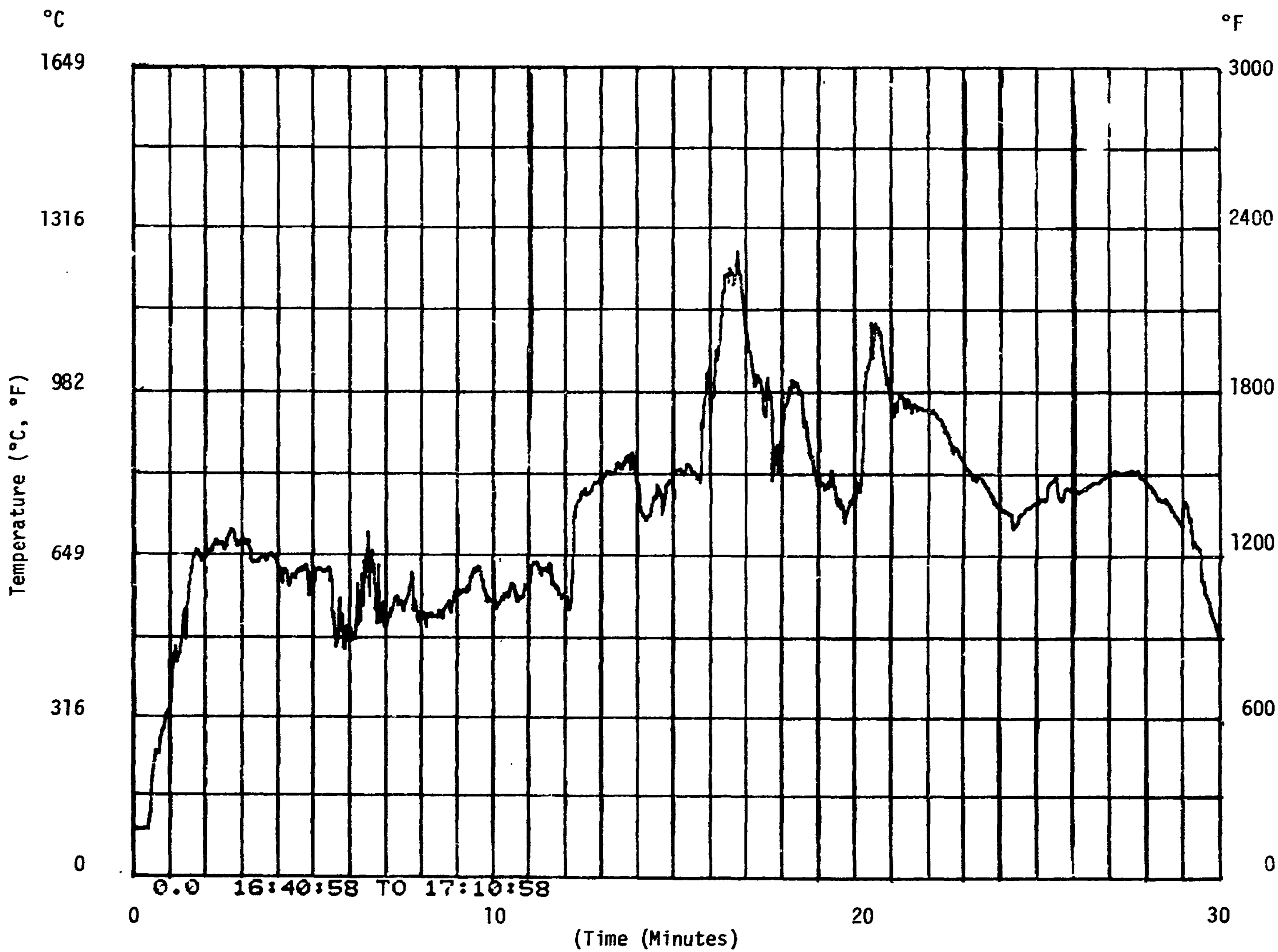


Figure K.12. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-2, 31 October 1979, Thermocouple Number 2.

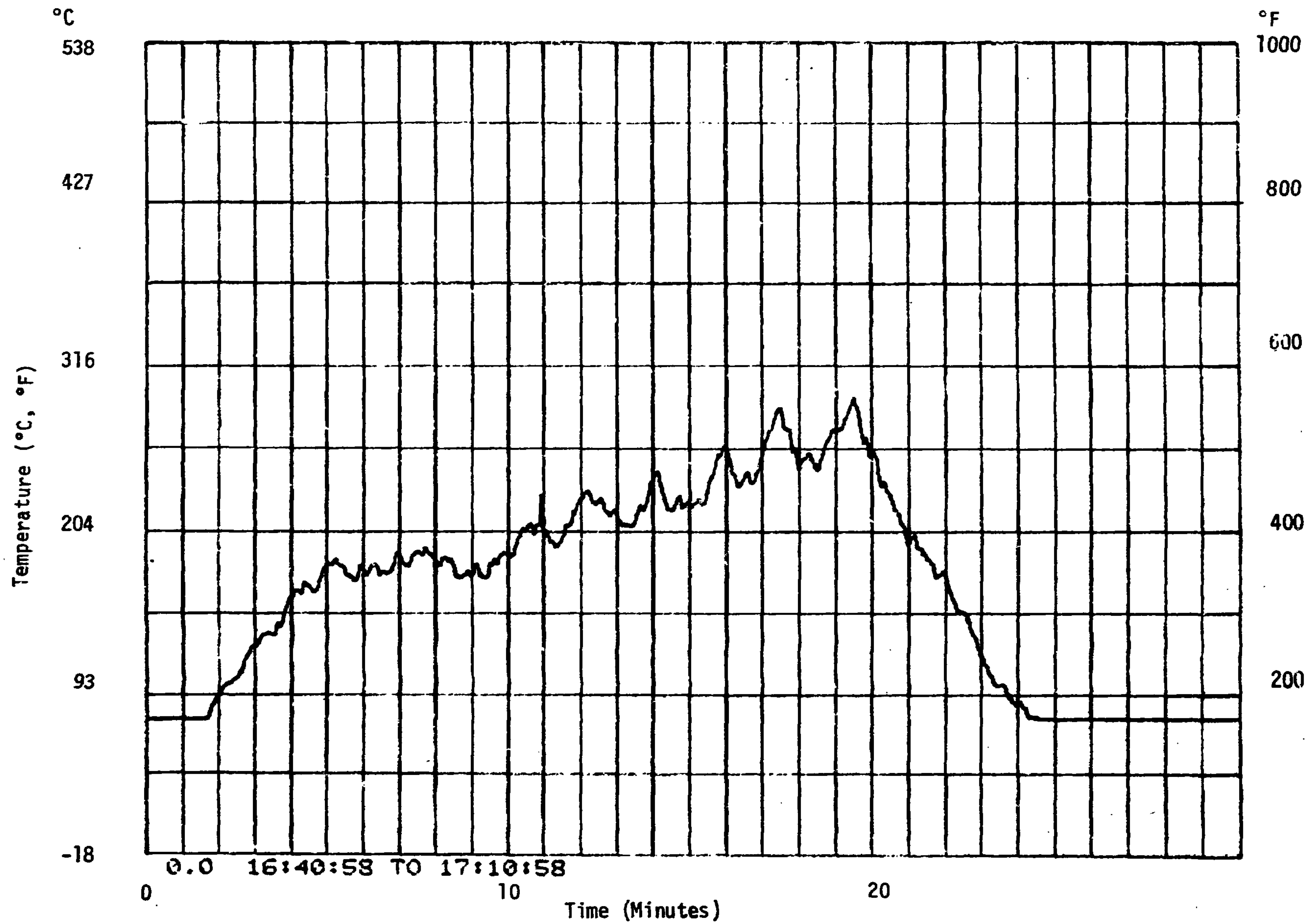


Figure K.13. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-2, 31 October 1979, Thermocouple Number 3.

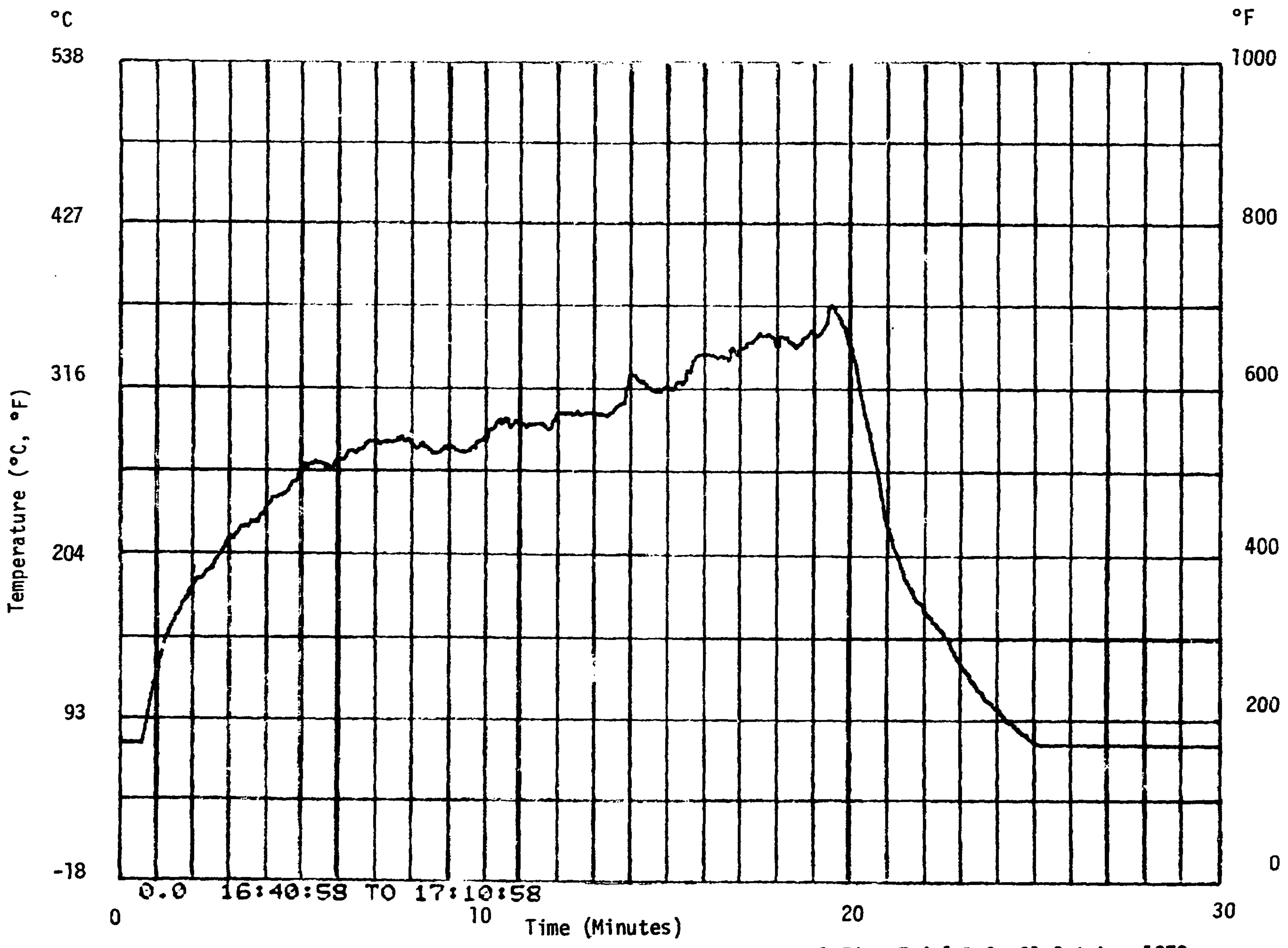


Figure K.14. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-2, 31 October 1979,

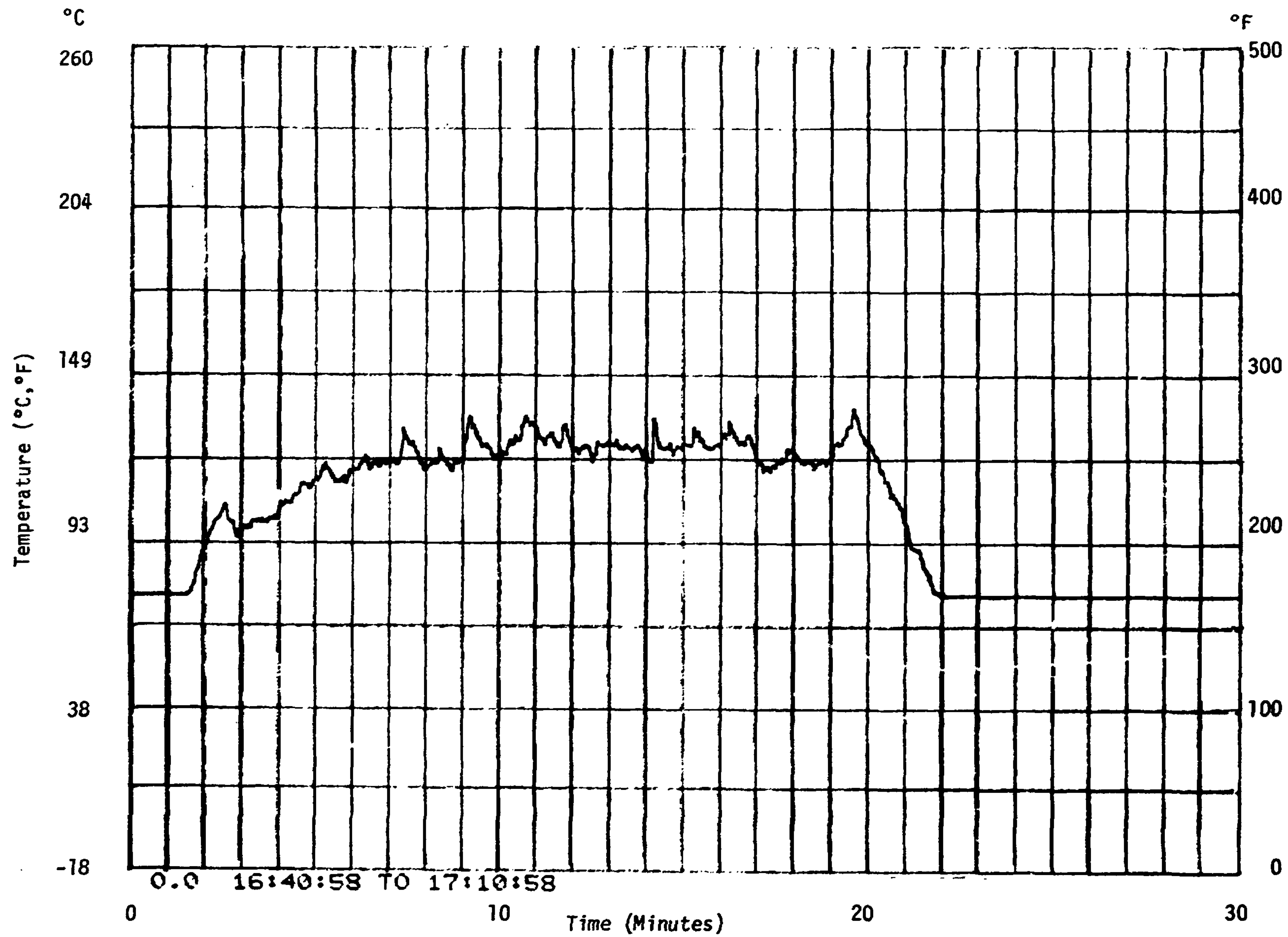


Figure K.15. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-2, 31 October 1979, Thermocouple Number 6.

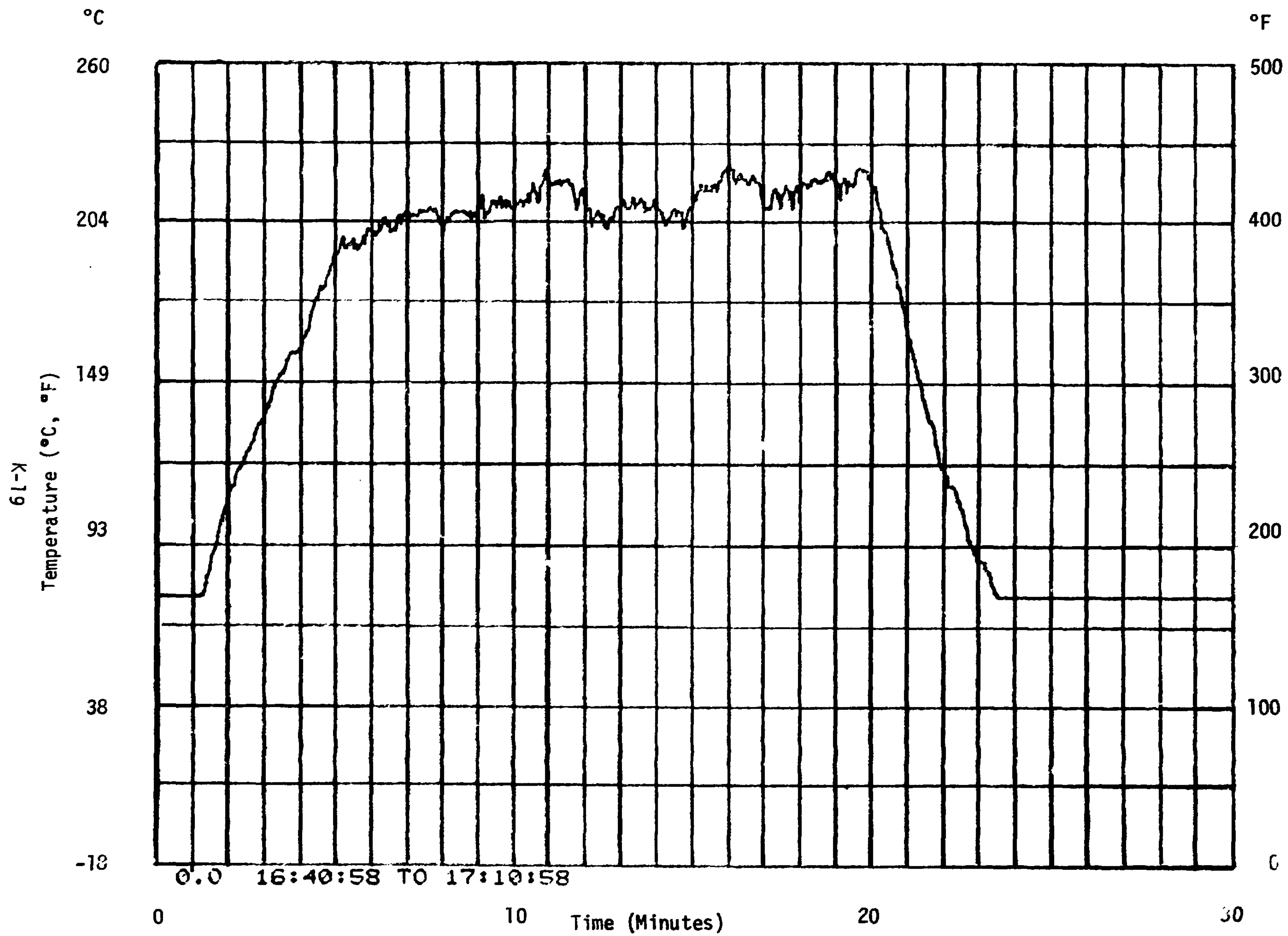


Figure K.16. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-2, 31 October 1979.

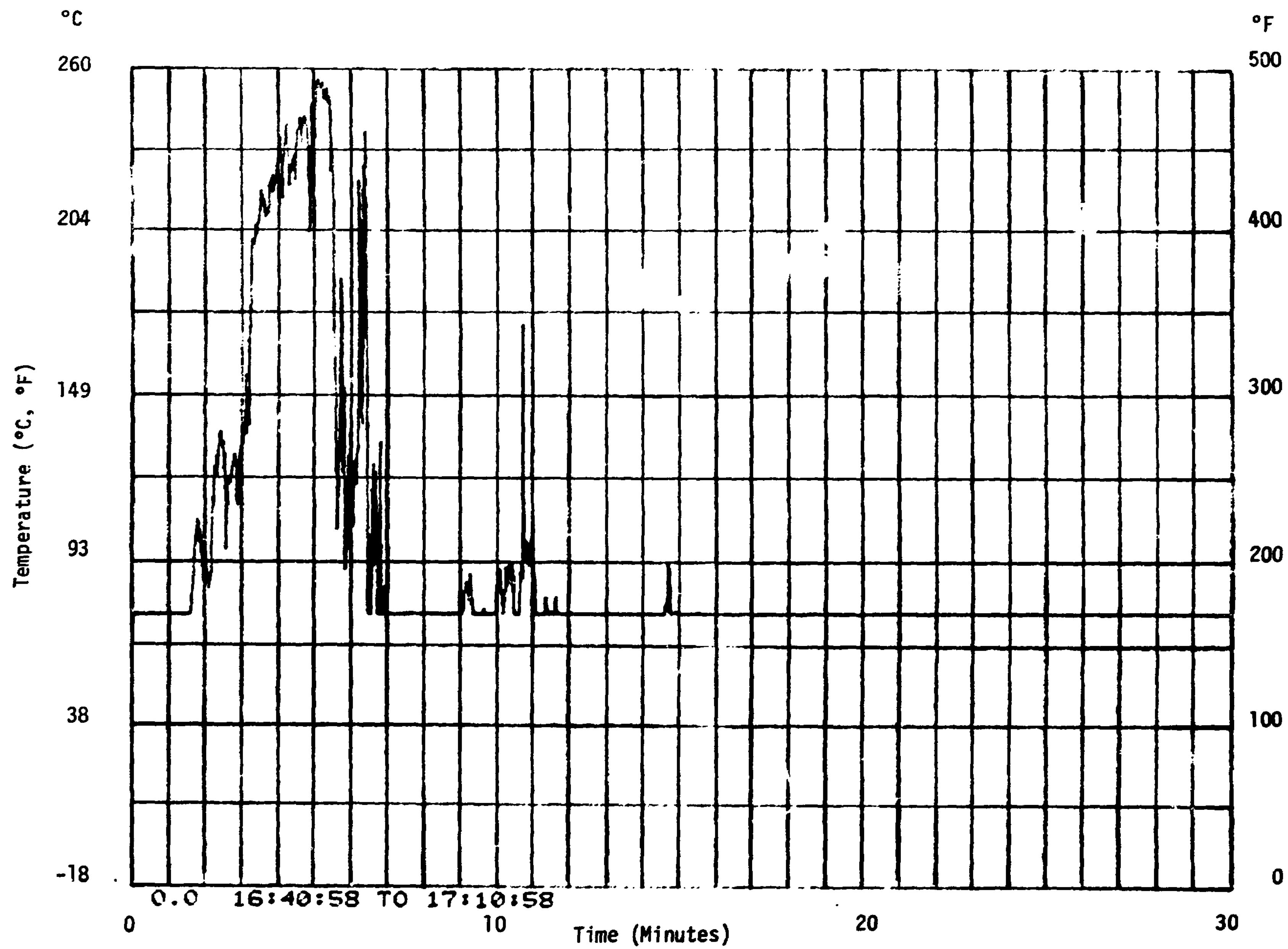


Figure K.17. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-2, 31 October 1979, Thermocouple Number 7.

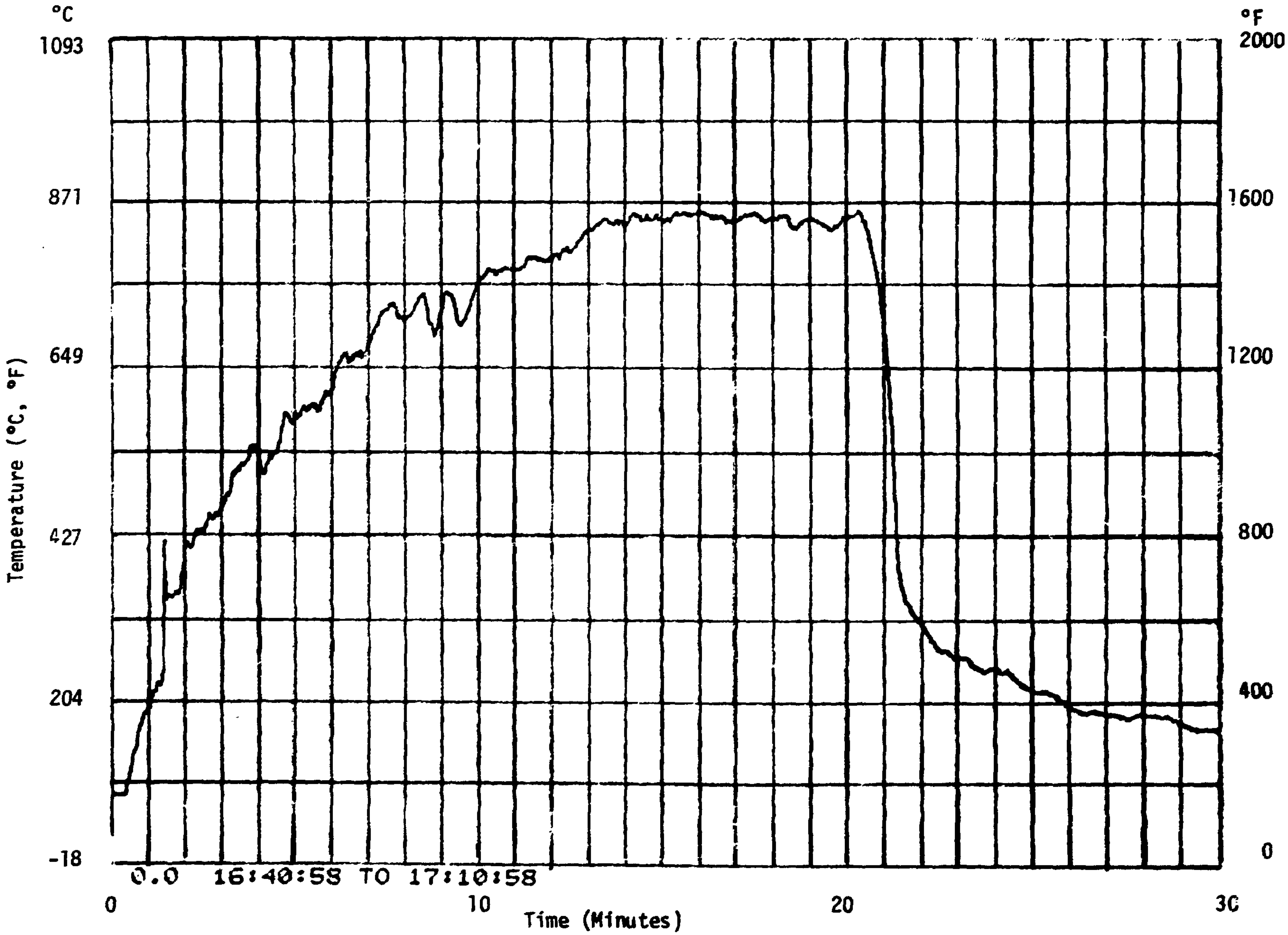


Figure K.18. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-2, 31 October 1979, Thermocouple Number 8.

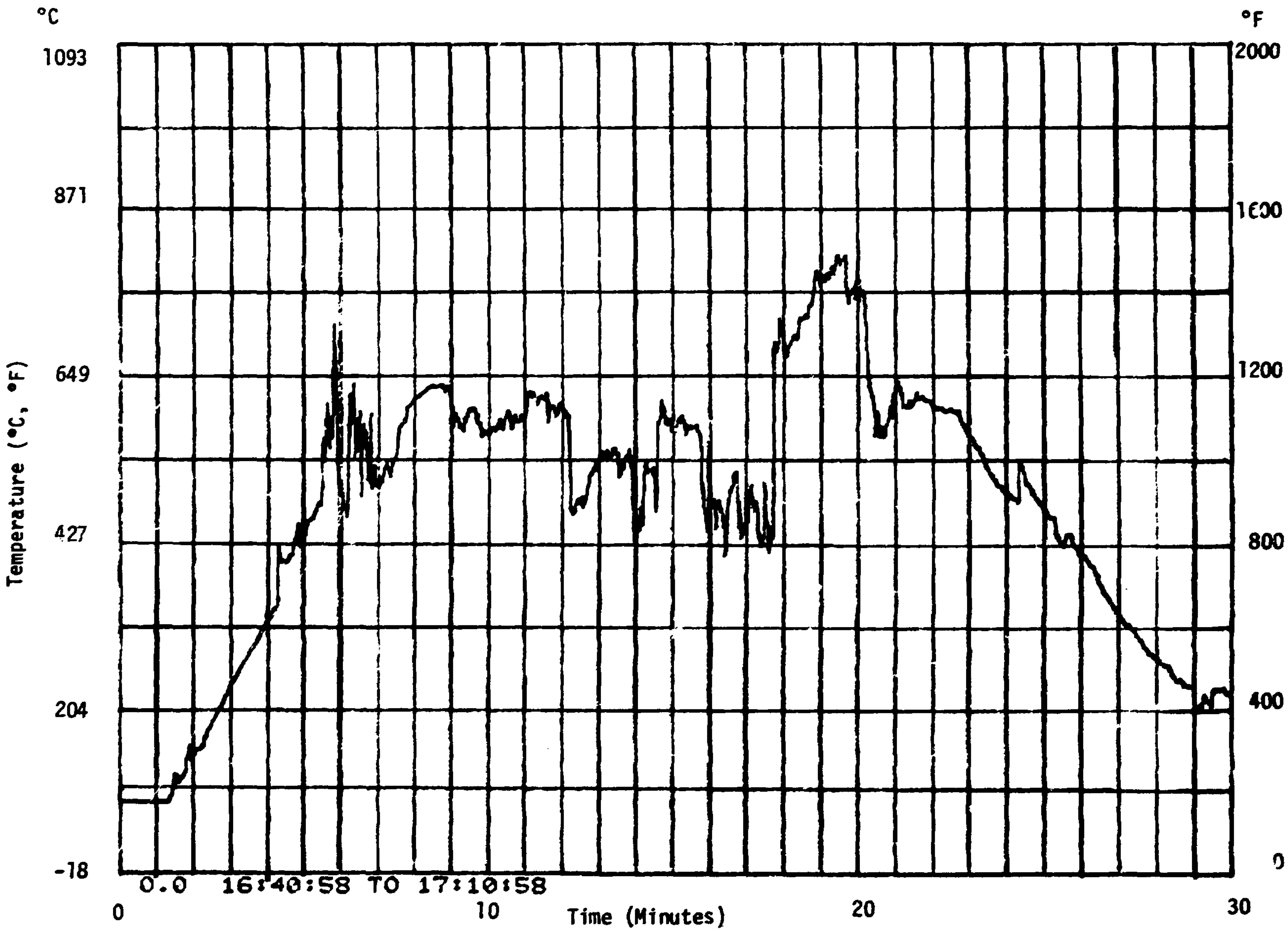


Figure K.19. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-2, 31 October 1979, Thermocouple Number 9.

Table K.3. Thermocouple Locations for NASA Carbon Fiber Pool Fire, Trial D-3, 9 November 1979.

Thermocouple Number	Specimen Number	Thermocouple Location
1	3-LH	On top inside
2	Ambient	In sleeve by 3-LH
3	3-LH	On top inside
4	3-LH	Underside
5	3-LH	In honeycomb
6	Ambient	Between 3-LH and 3-LV
7	Ambient	On guy wire NW of pool
8	3-RV	On top inside
9	3-RV	On top inside
11[a]	3-LV	On top inside
12[a]	3-LV	On top inside
13	Ambient	In sleeve by 3RH
14	3RH	On top inside
15	3RH	On top inside
16	3RH	Underside

NOTE: Thermocouple and specimen locations are shown in Figure K.20.

[a]Thermocouples number 11 and 12 did not function.

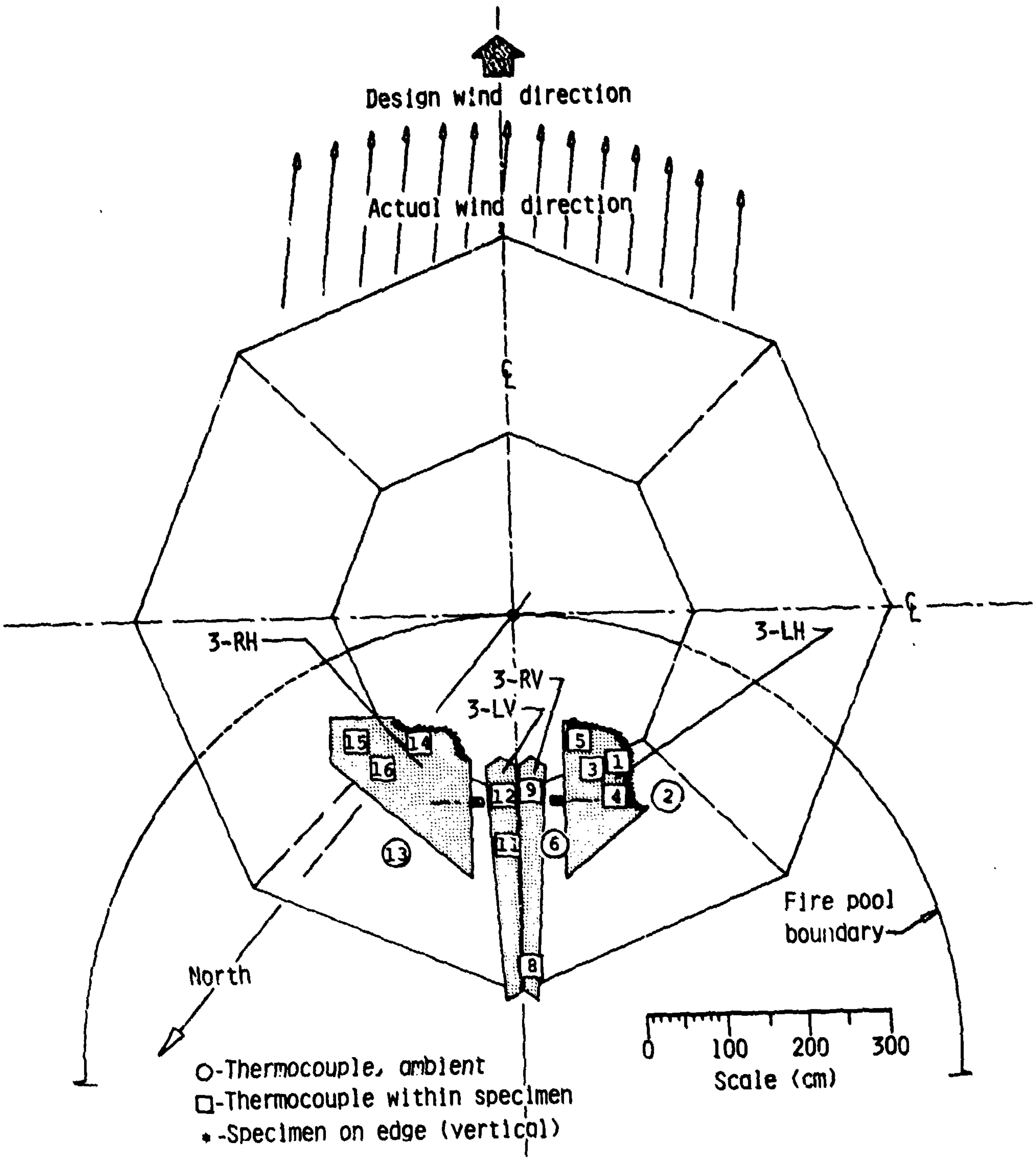


Figure K.20. Thermocouple Location for Pool Fire D-3, 9 November 1979.

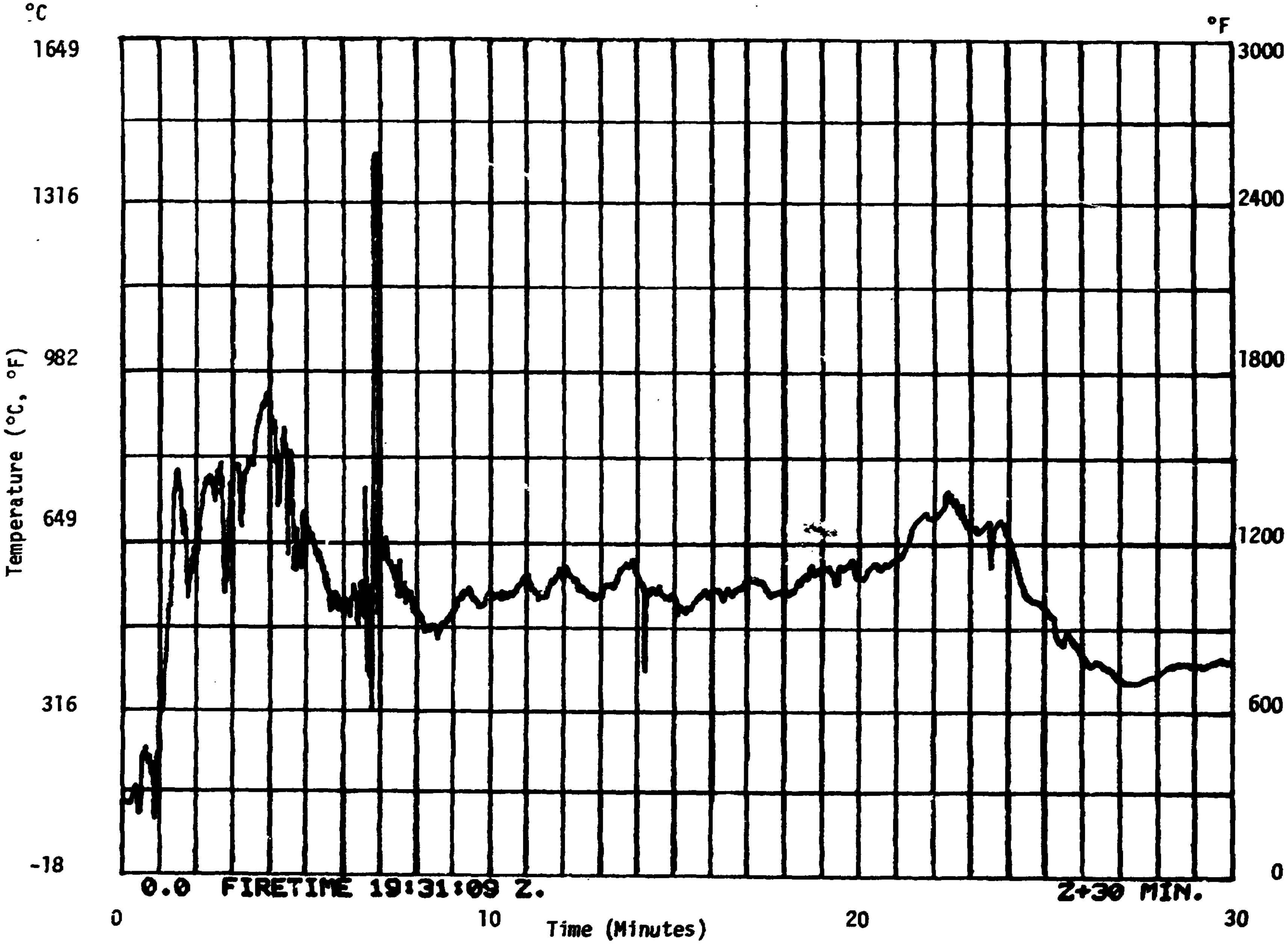


Figure K.21. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-3, 9 November 1979, Thermocouple Number 1.

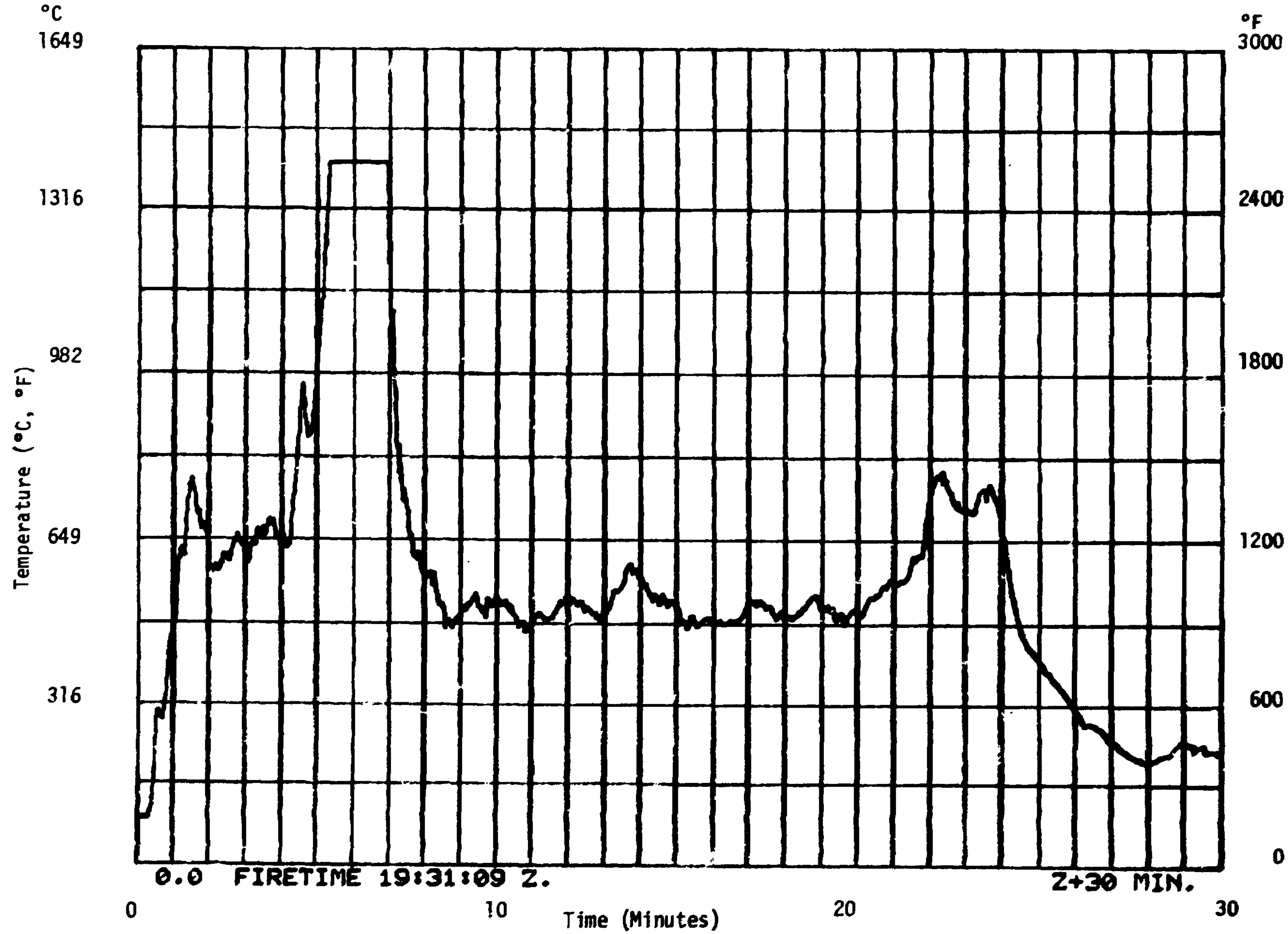


Figure K.22. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-3, 9 November 1979, Thermocouple Number 2.

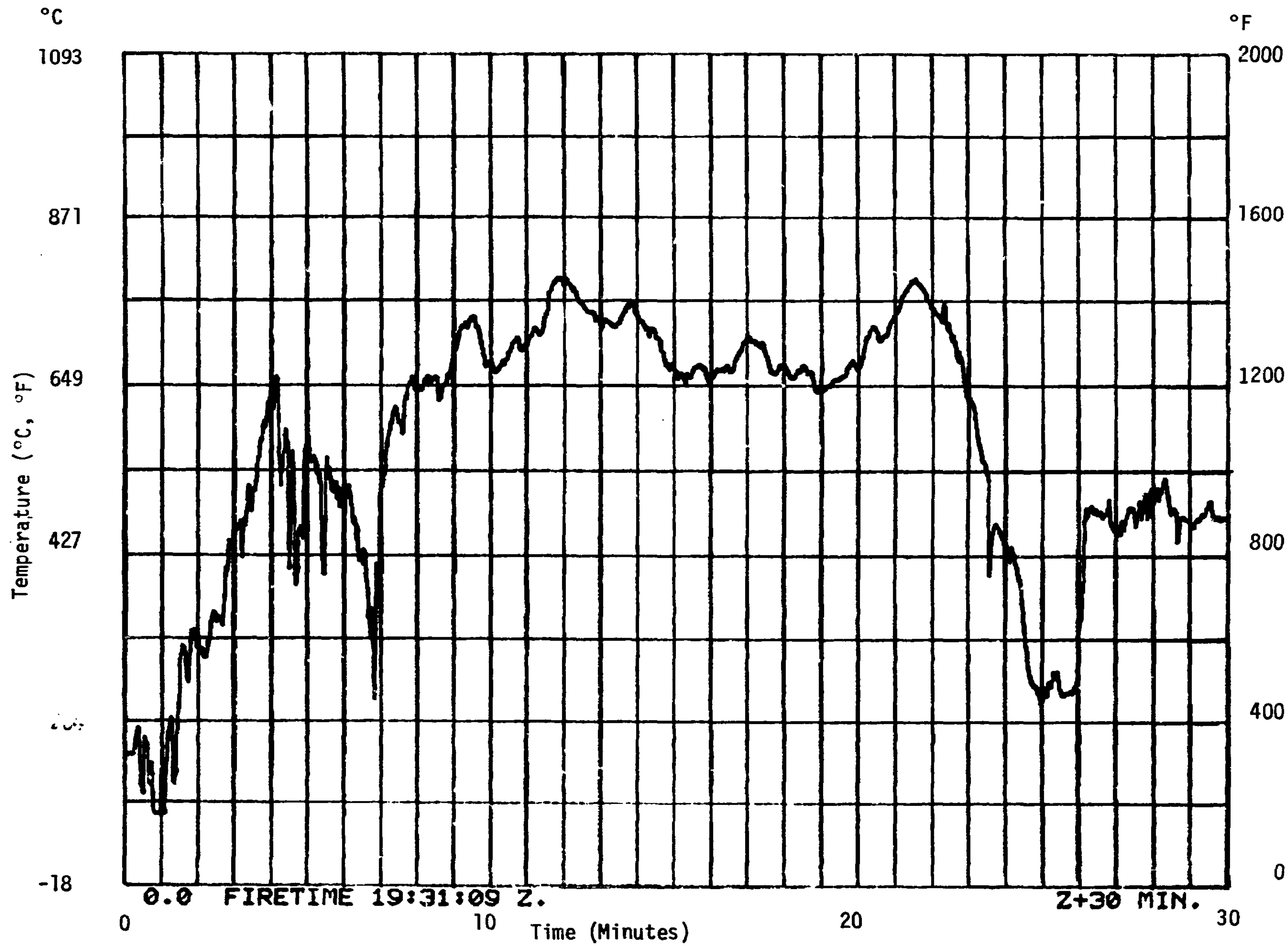


Figure K.23. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-3, 9 November 1979, Thermocouple Number 3.

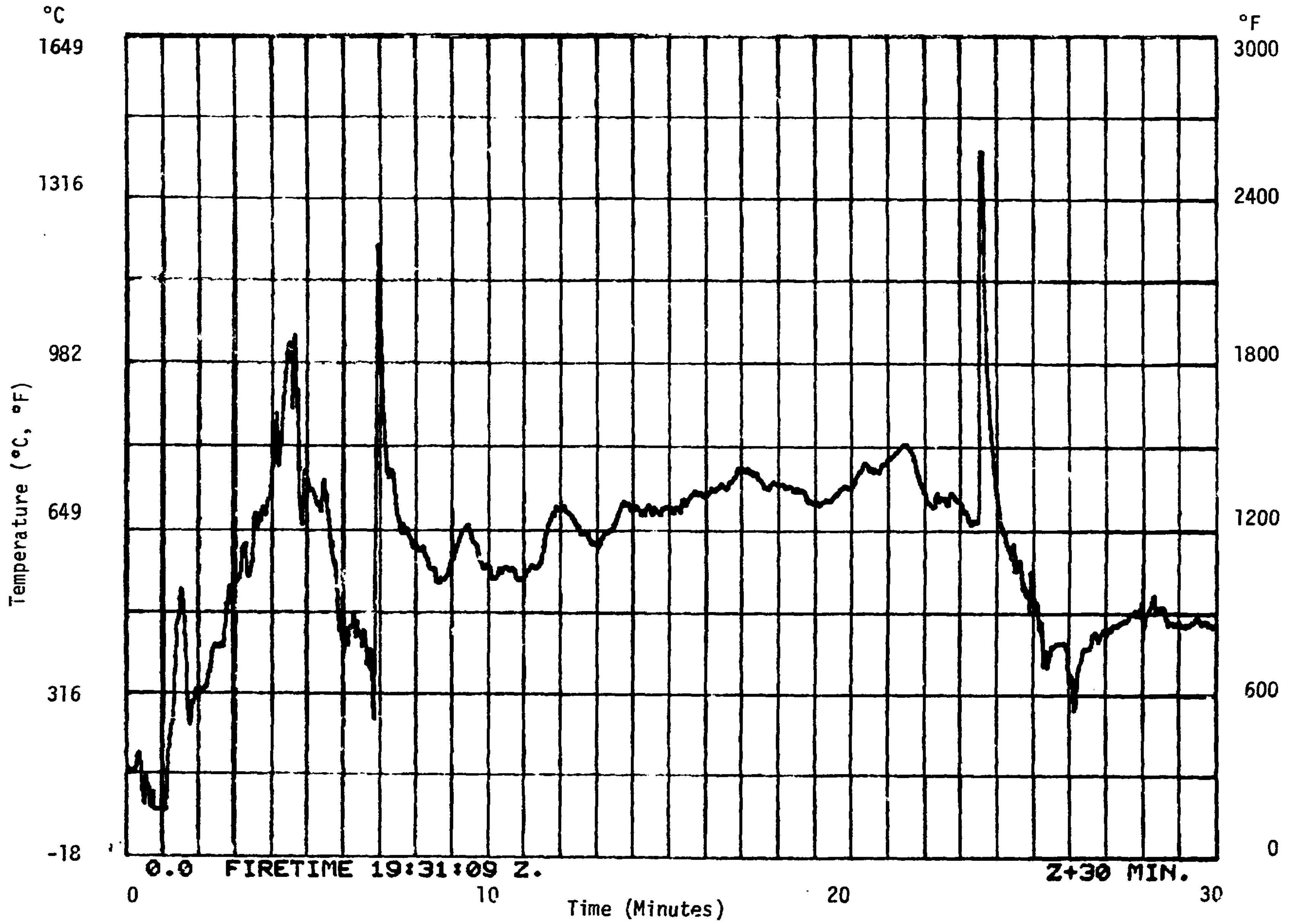


Figure K.24. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-3, 9 November 1979, Thermocouple Number 4.

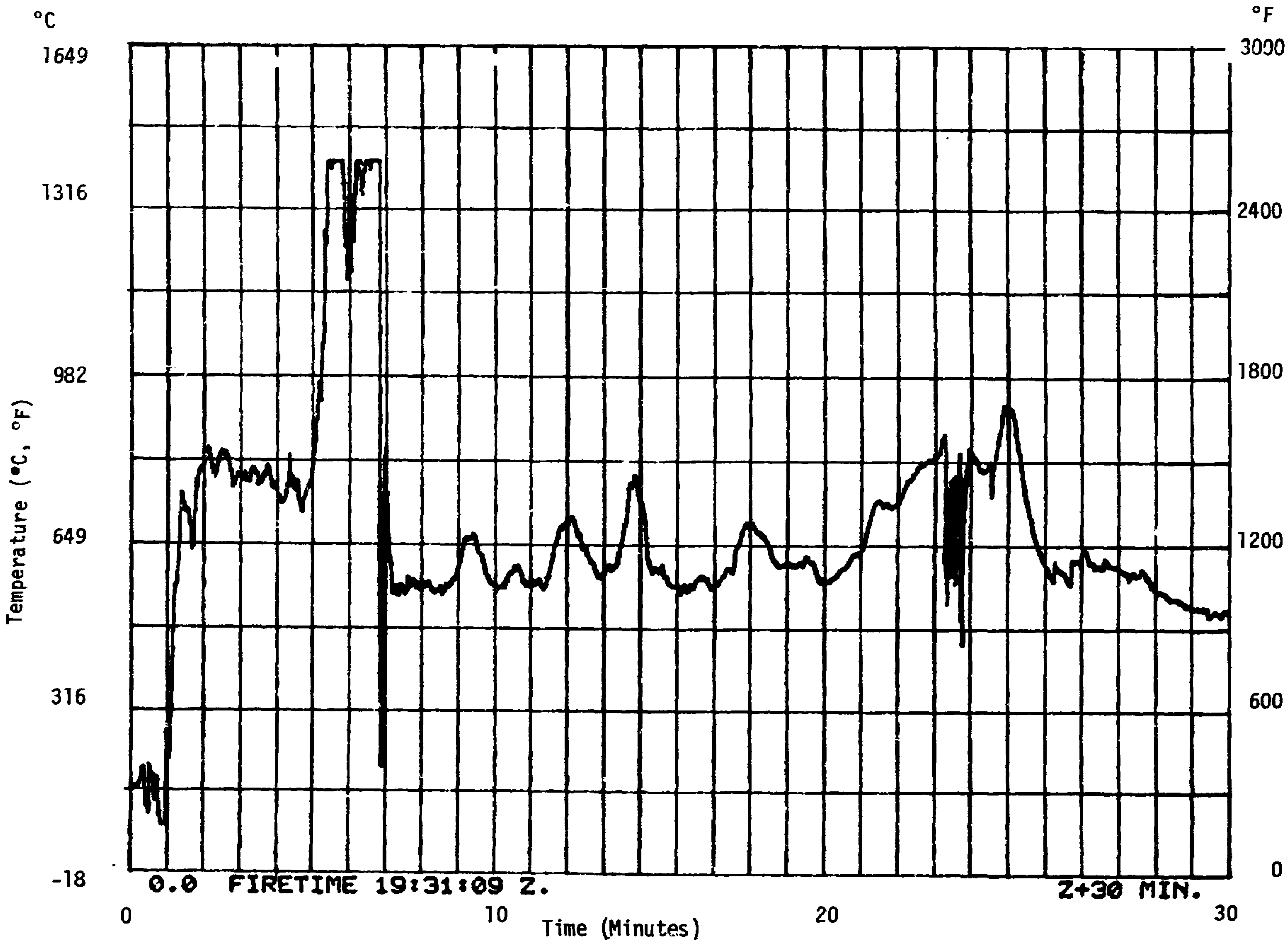


Figure K.25. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-3, 9 November 1979, Thermocouple Number 5.

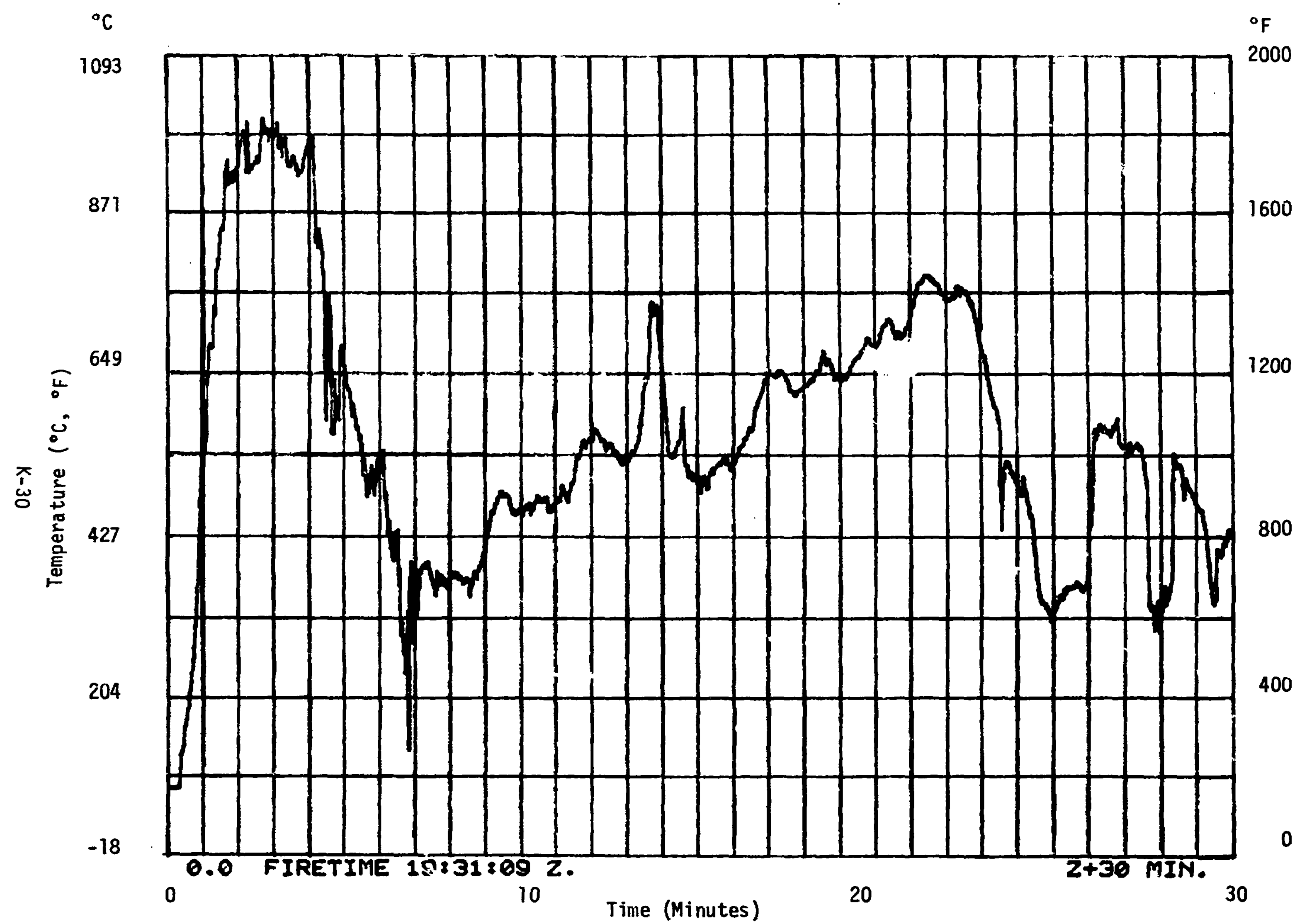


Figure K.26. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-3, 9 November 1979, Thermocouple Number 6.

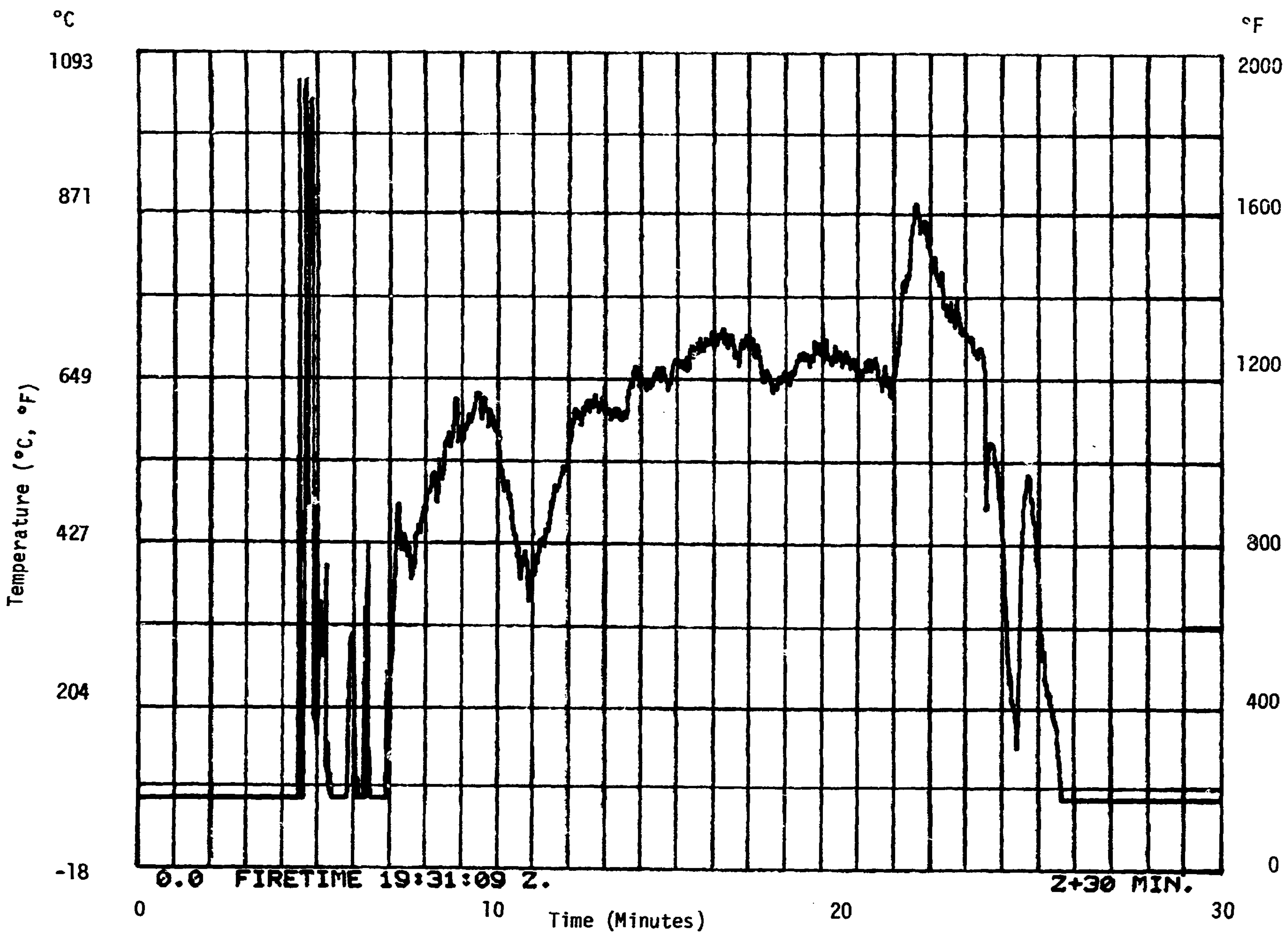


Figure K.27. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-3, 9 November 1979, Thermocouple Number 7.

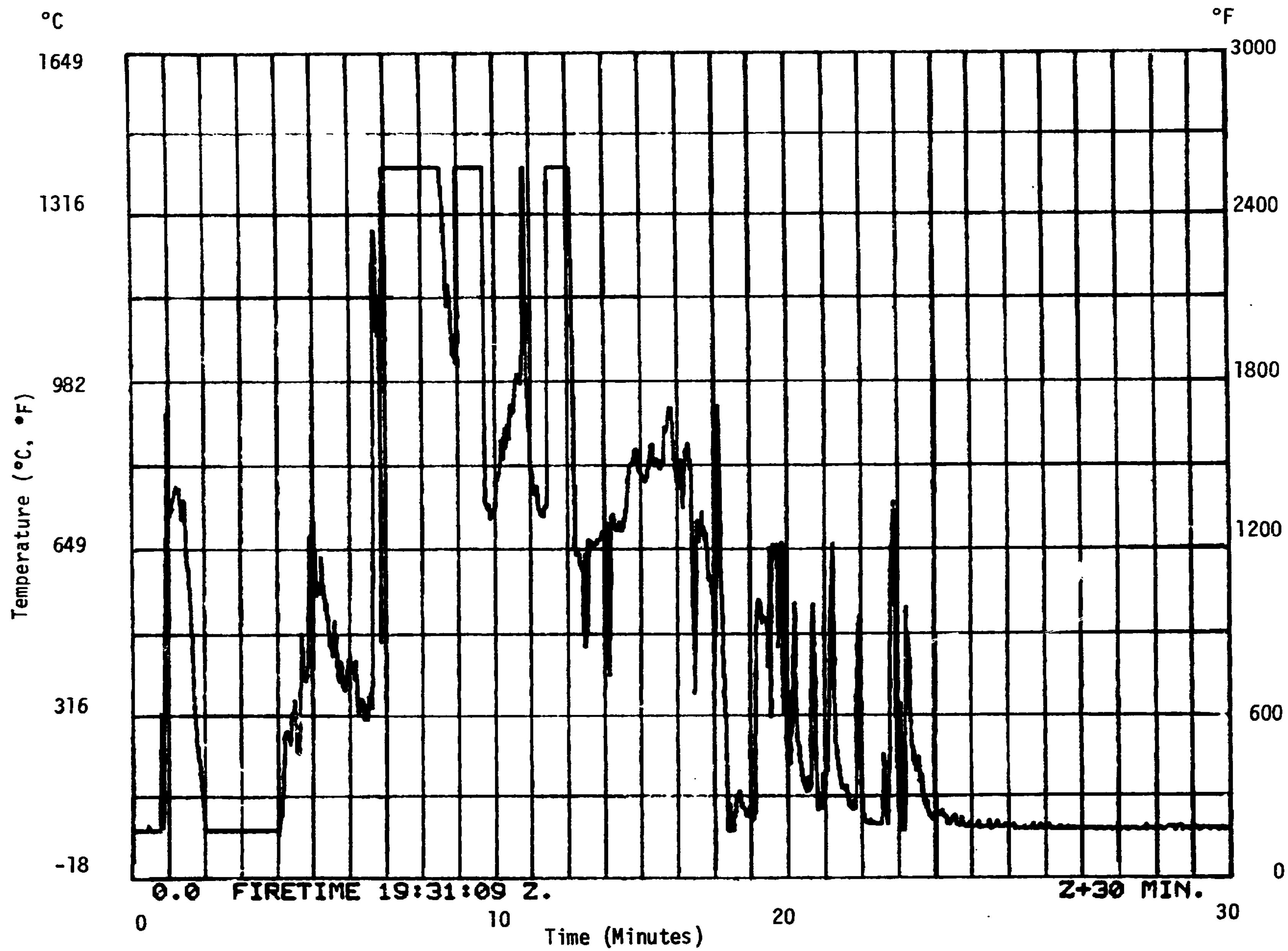


Figure K.28. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-3, 9 November 1979, Thermocouple Number 8.

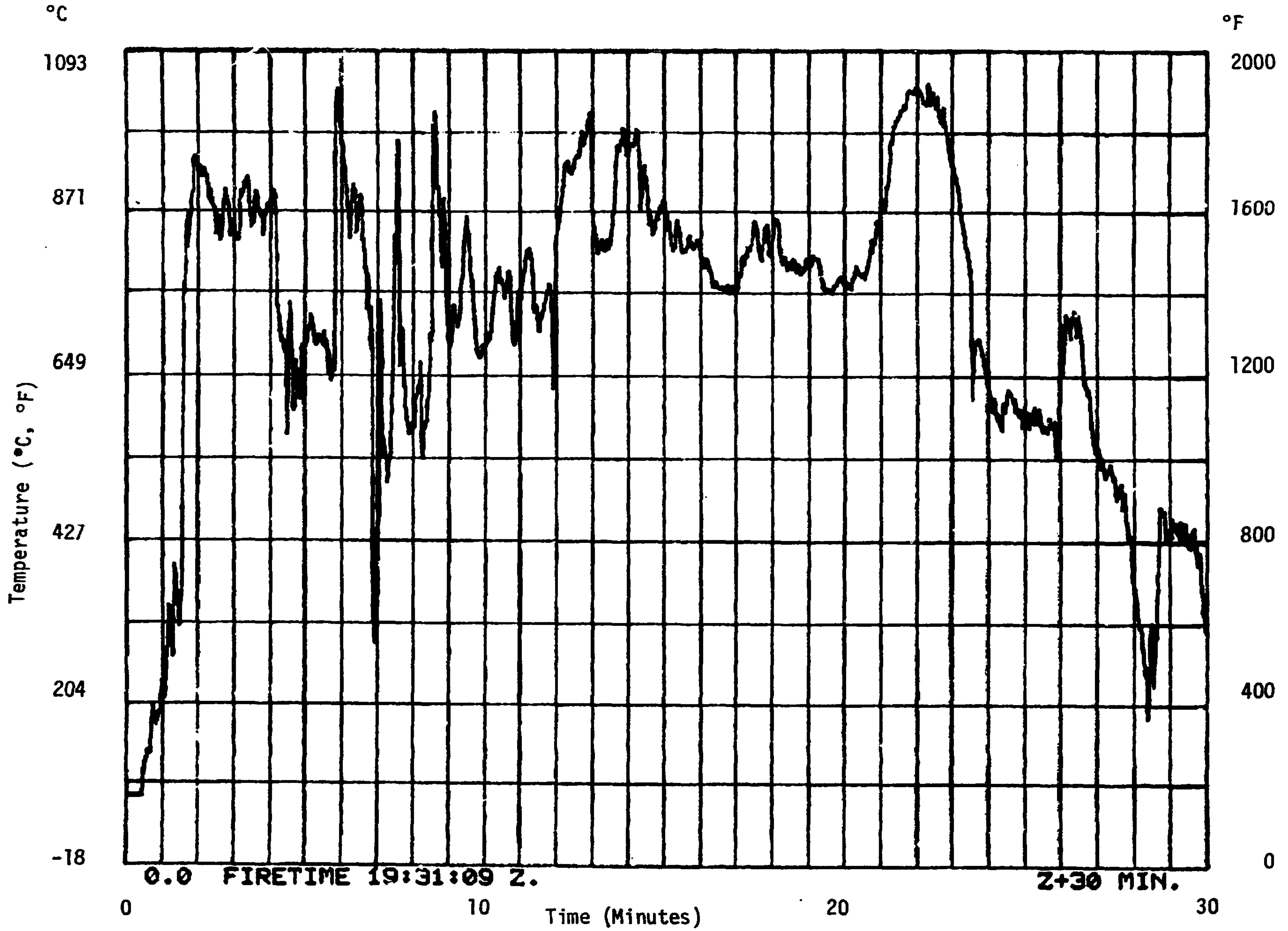


Figure K.29. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-3, 9 November 1979, Thermocouple Number 9.

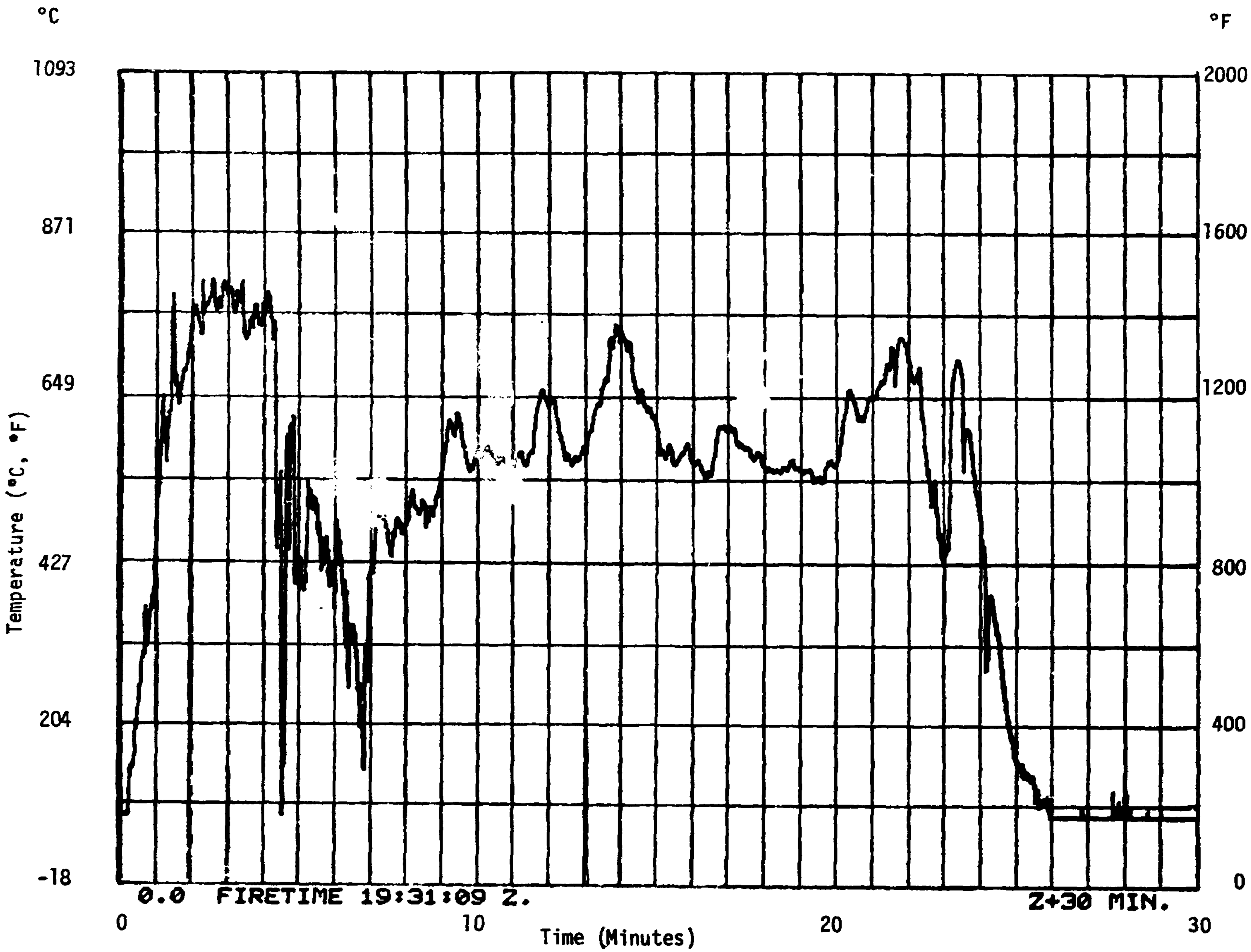


Figure K.30. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-3, 9 November 1979, Thermocouple Number 13.

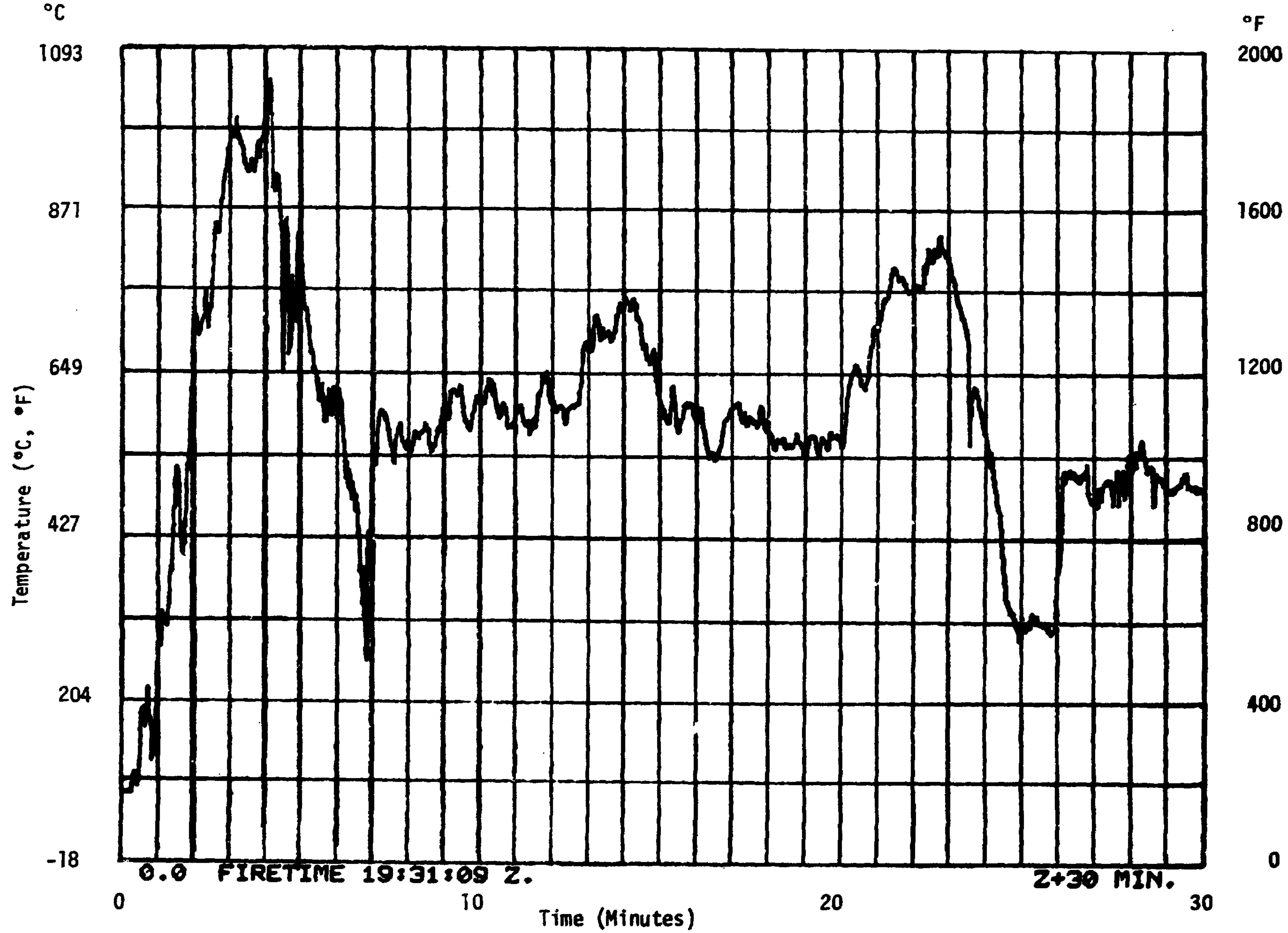


Figure K.31. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-3, 9 November 1979, Thermocouple Number 14.

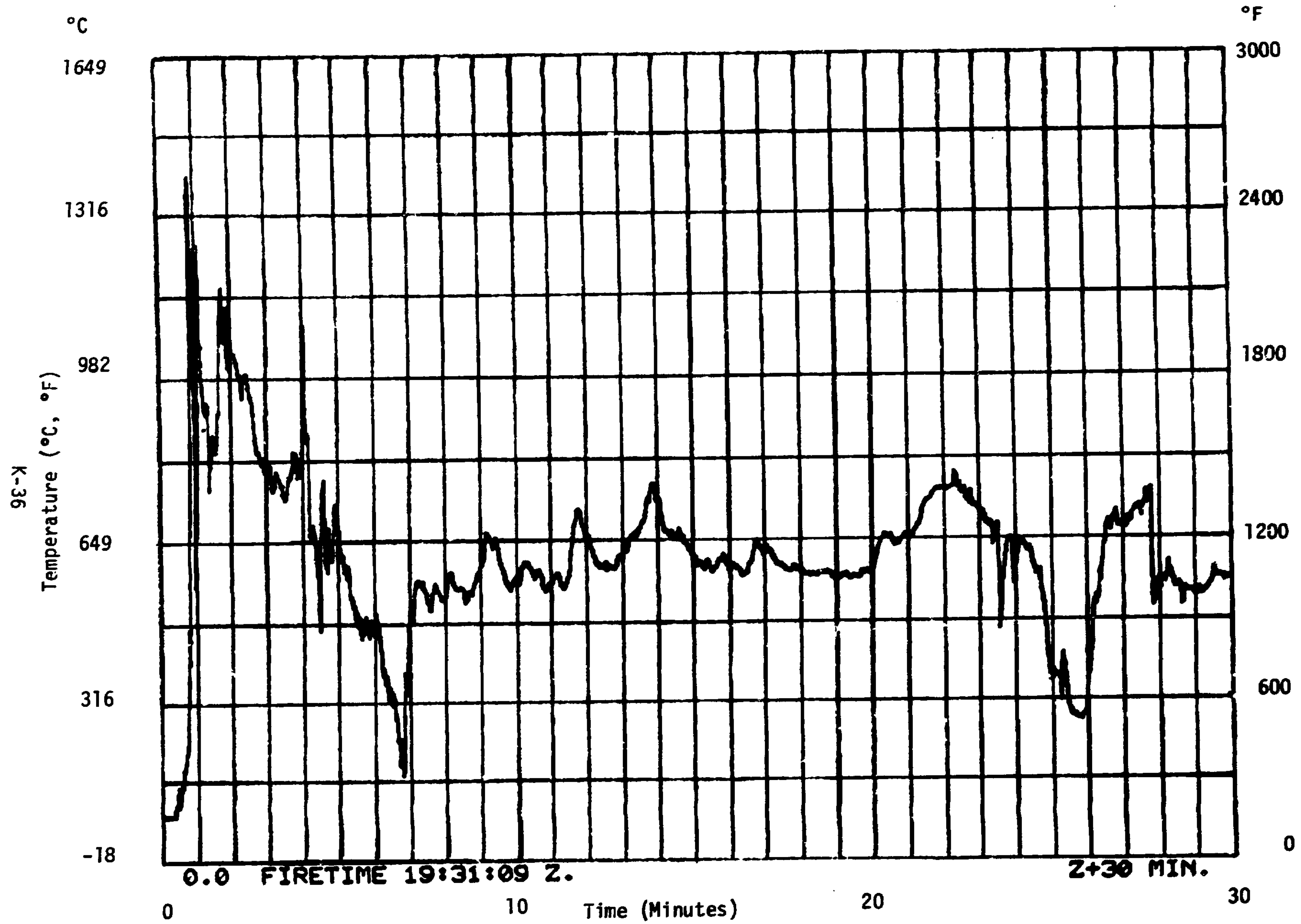


Figure K.32. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-3, 9 November 1979, Thermocouple Number 15.

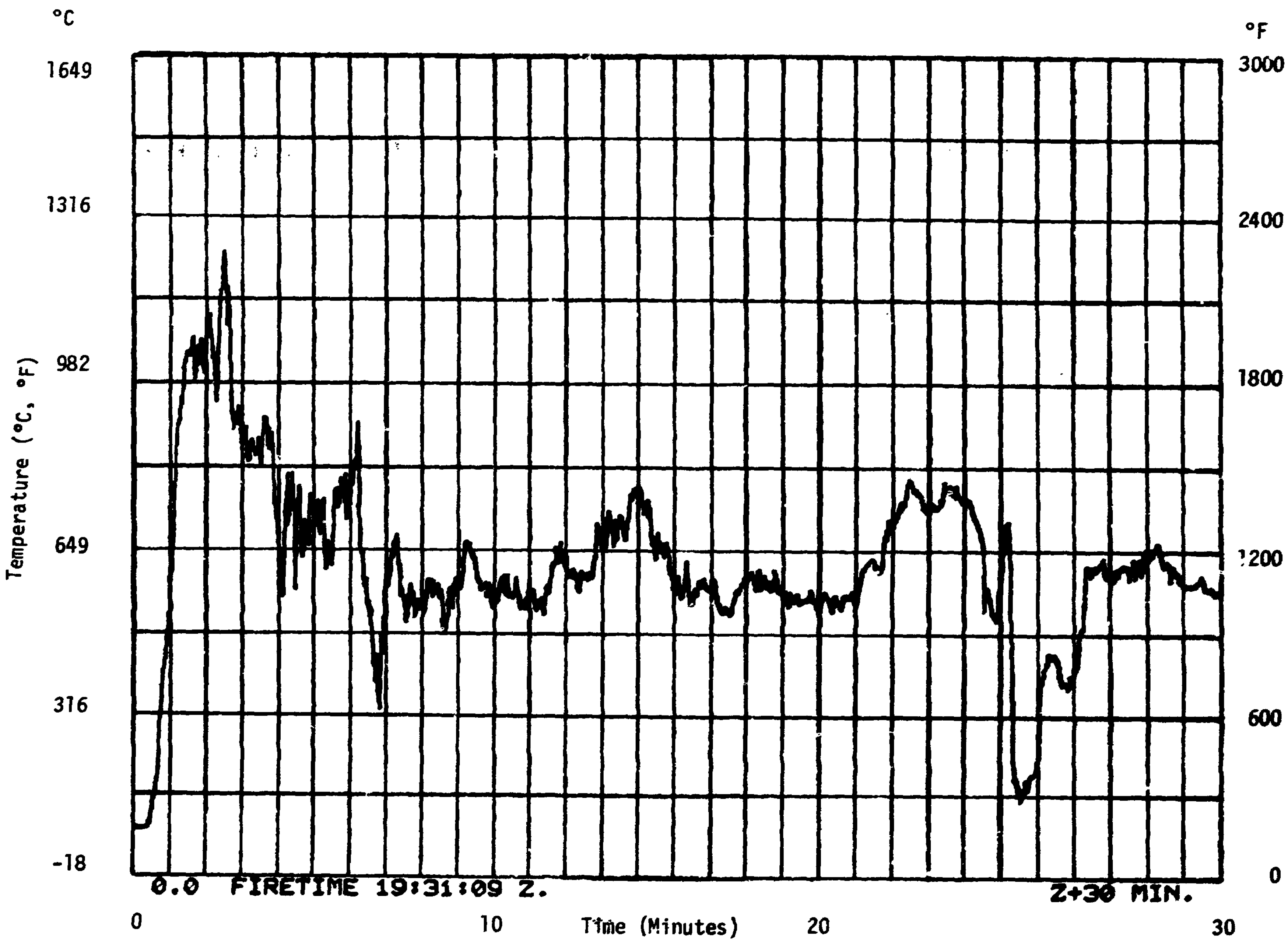


Figure K.33. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial D-3, 9 November 1979, Thermocouple Number 16.

Table K.4. Thermocouple Loacations for NASA Carbon Fiber Pool Fire, Trial S-1, 15 November 1979.

Thermocouple Number	Specimen Number	Thermocouple Location
1	3-1	Inside speed brake
2	Ambient	In sleeve by speed brake
3	3-5	Inside specimen
4	Ambient	In sleeve by specimen
5	3-6 & 3-7	Between specimen
6	Ambient	In sleeve by specimen
7	3-11	Inside specimen
8	Ambient	In sleeve by specimen
9	Ambient	On guy wire near pool
13	Peterson Sampler	Inside sampler number 12-13
14	Peterson Sampler	Inside sampler number 12-9

NOTE: Thermocouple and specimen locations are shown in Figure K.34.

Thermocouples TC9 and TC14 did not record temperatures greater than 76°C.

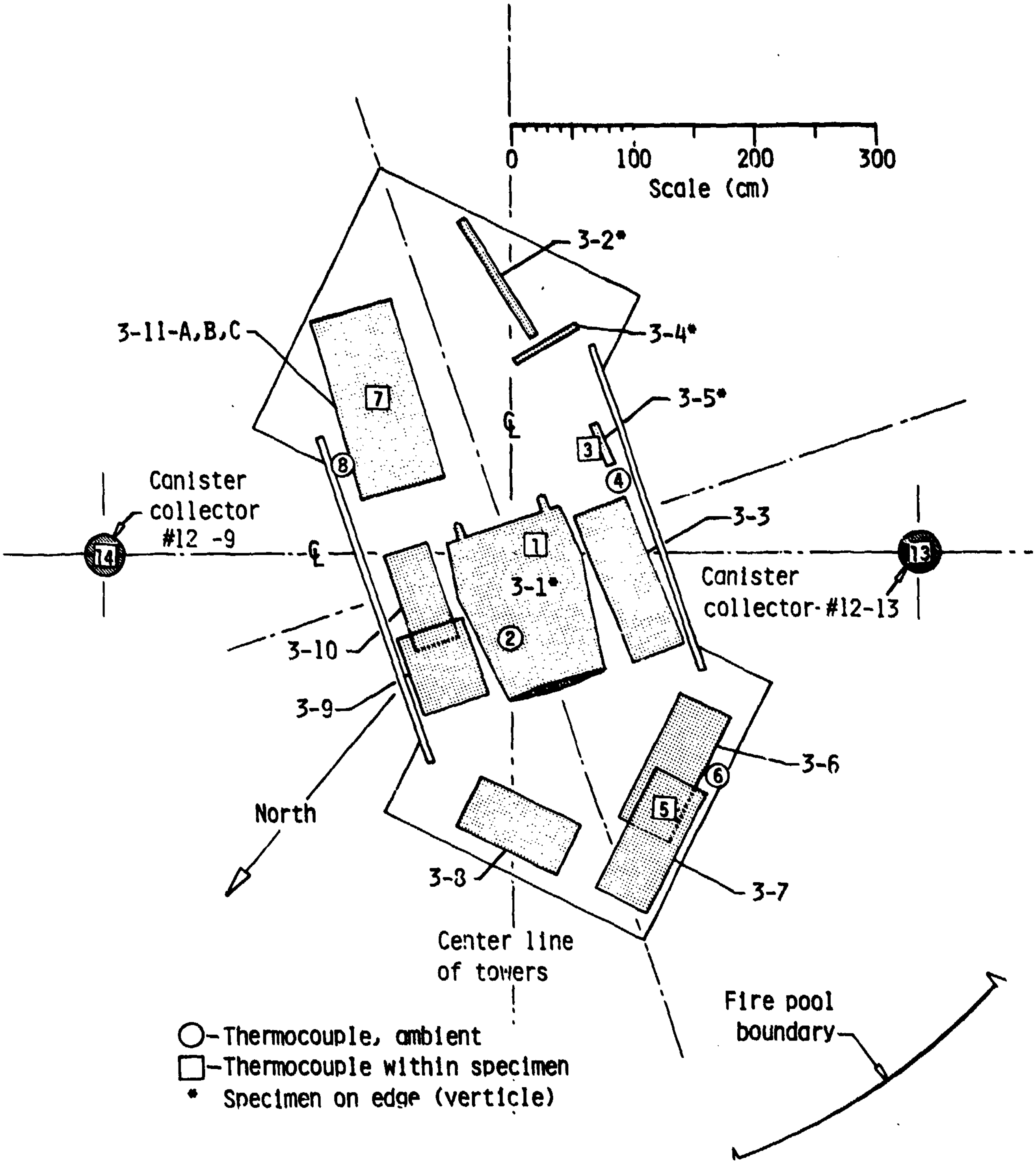


Figure K.34. Thermocouple Locations for Pool Fire S-1,
15 November 1979.

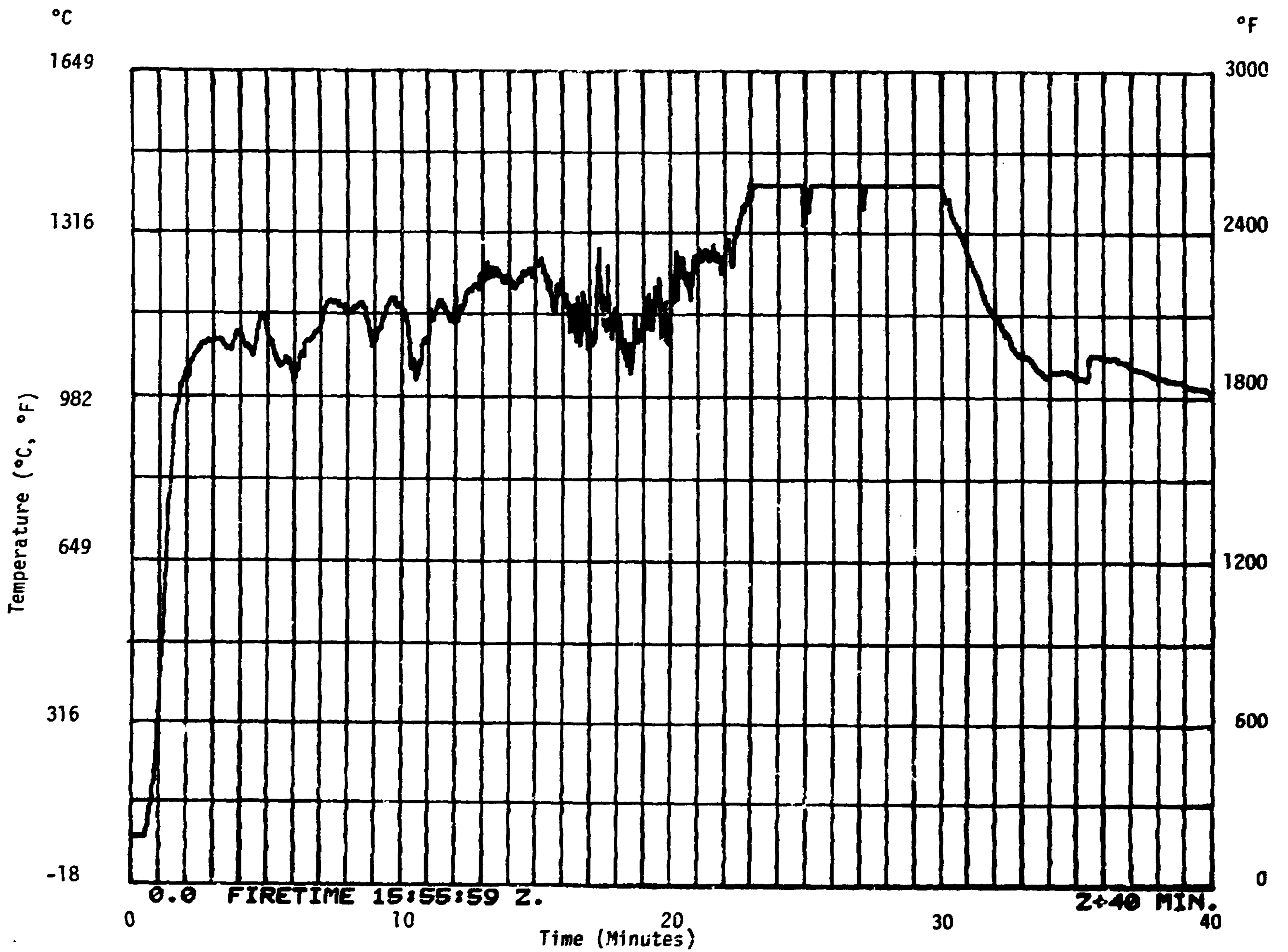


Figure K.35. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial S-1, 15 November 1979, Thermocouple Number 1.

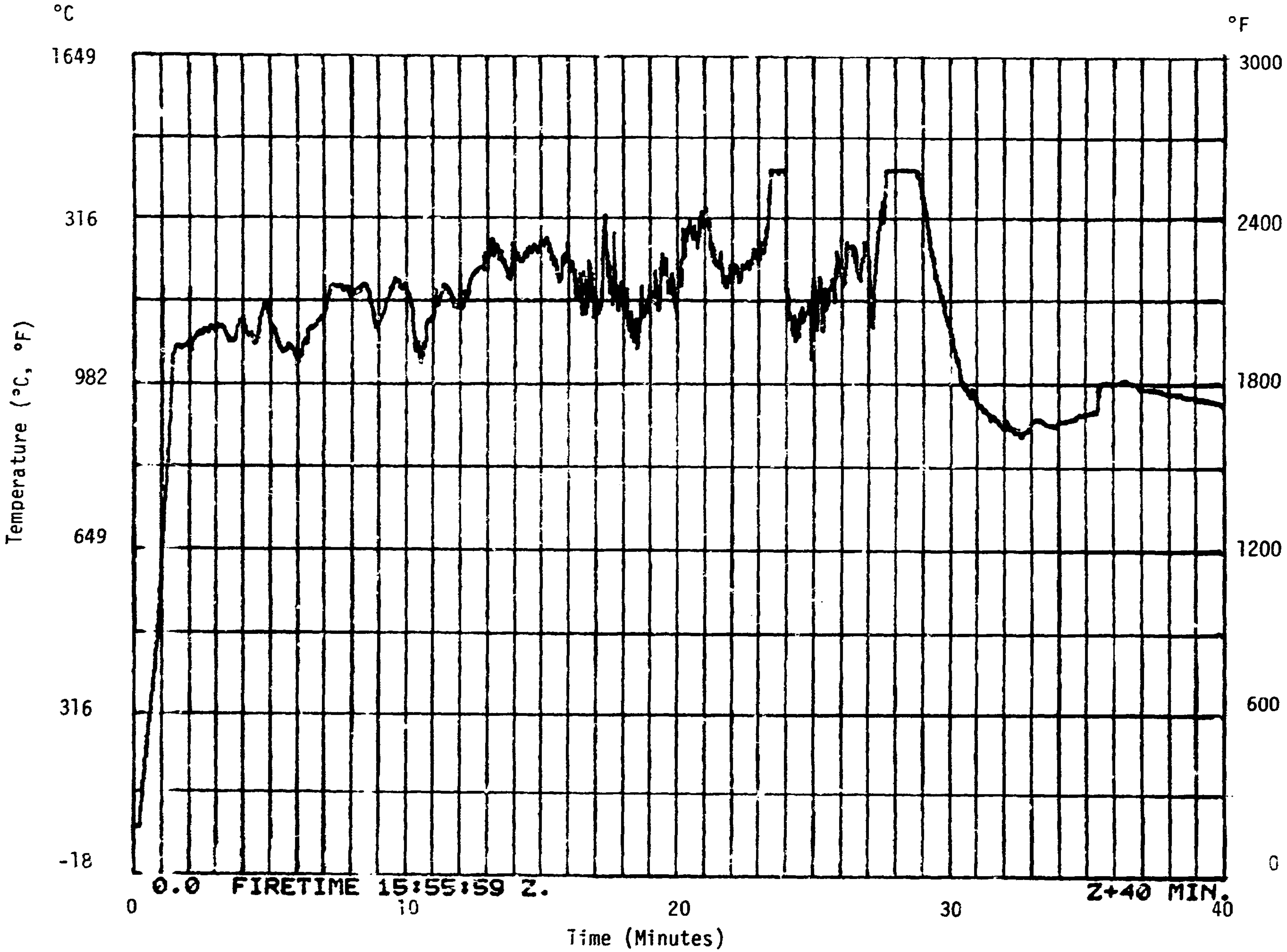


Figure K.36. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial S-1, 15 November 1979,

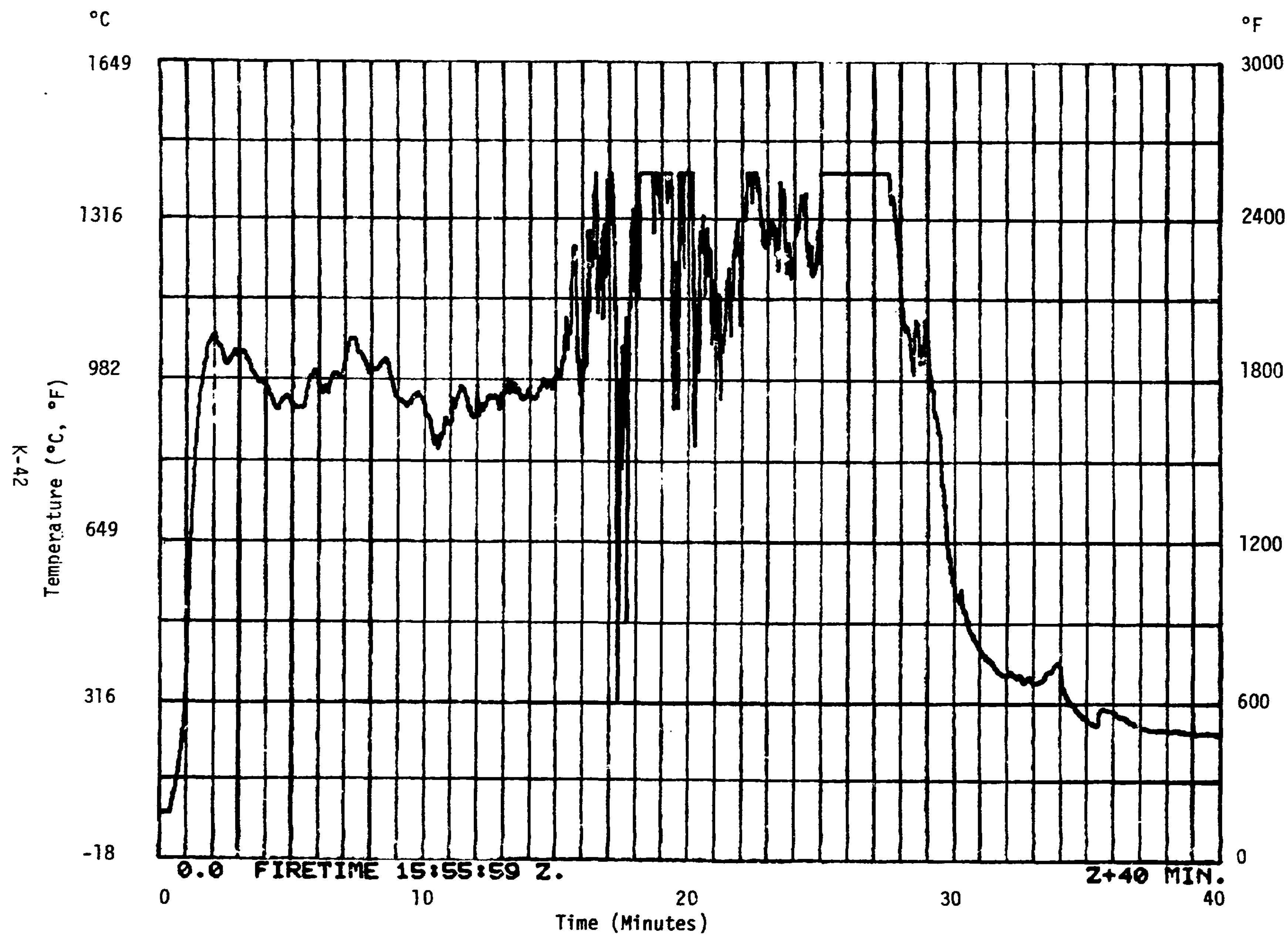


Figure K.37. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial S-1, 15 November 1979, Thermocouple Number 3.

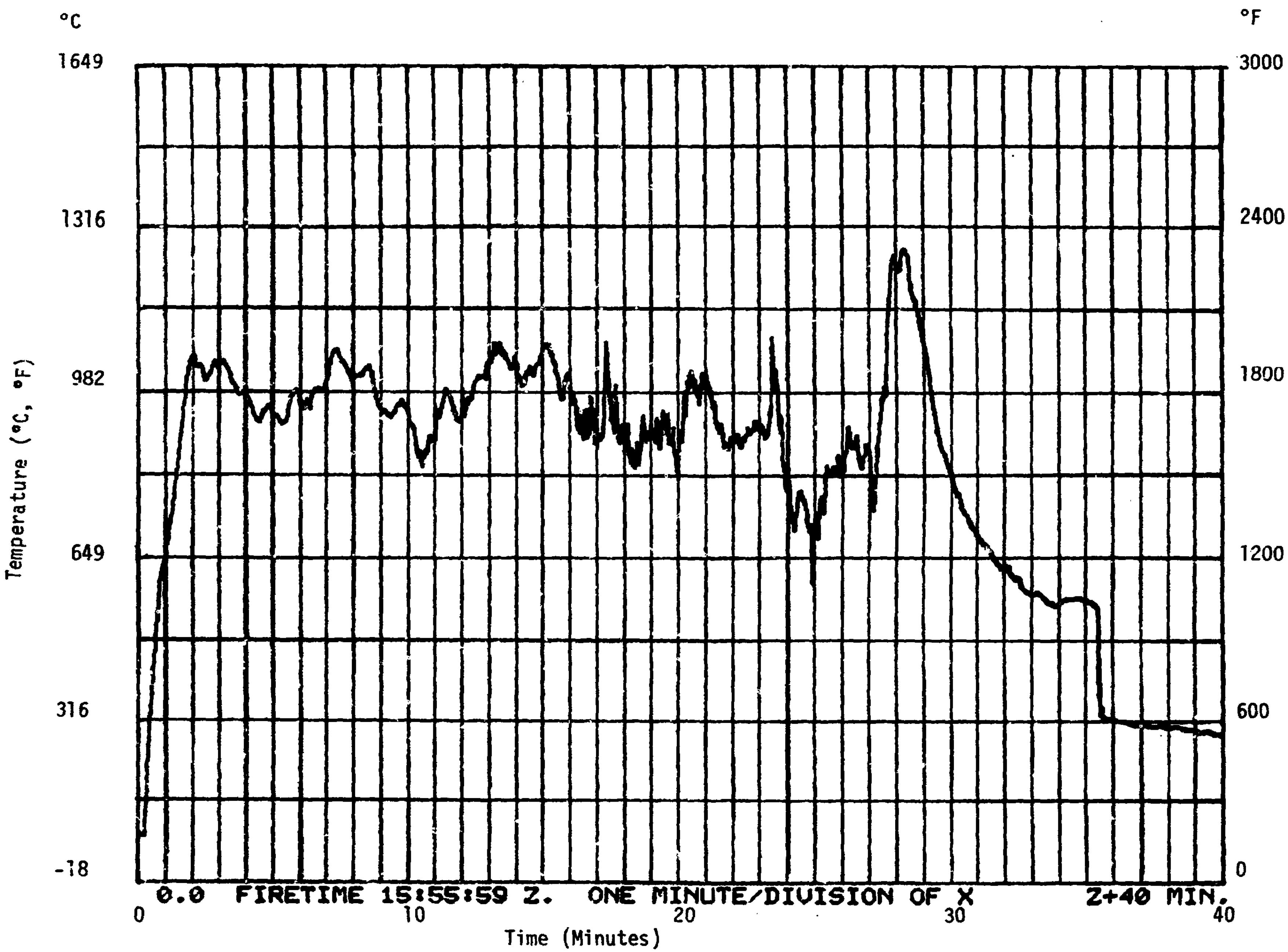


Figure K.38. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial S-1, 15 November 1979, Thermocouple Number 4

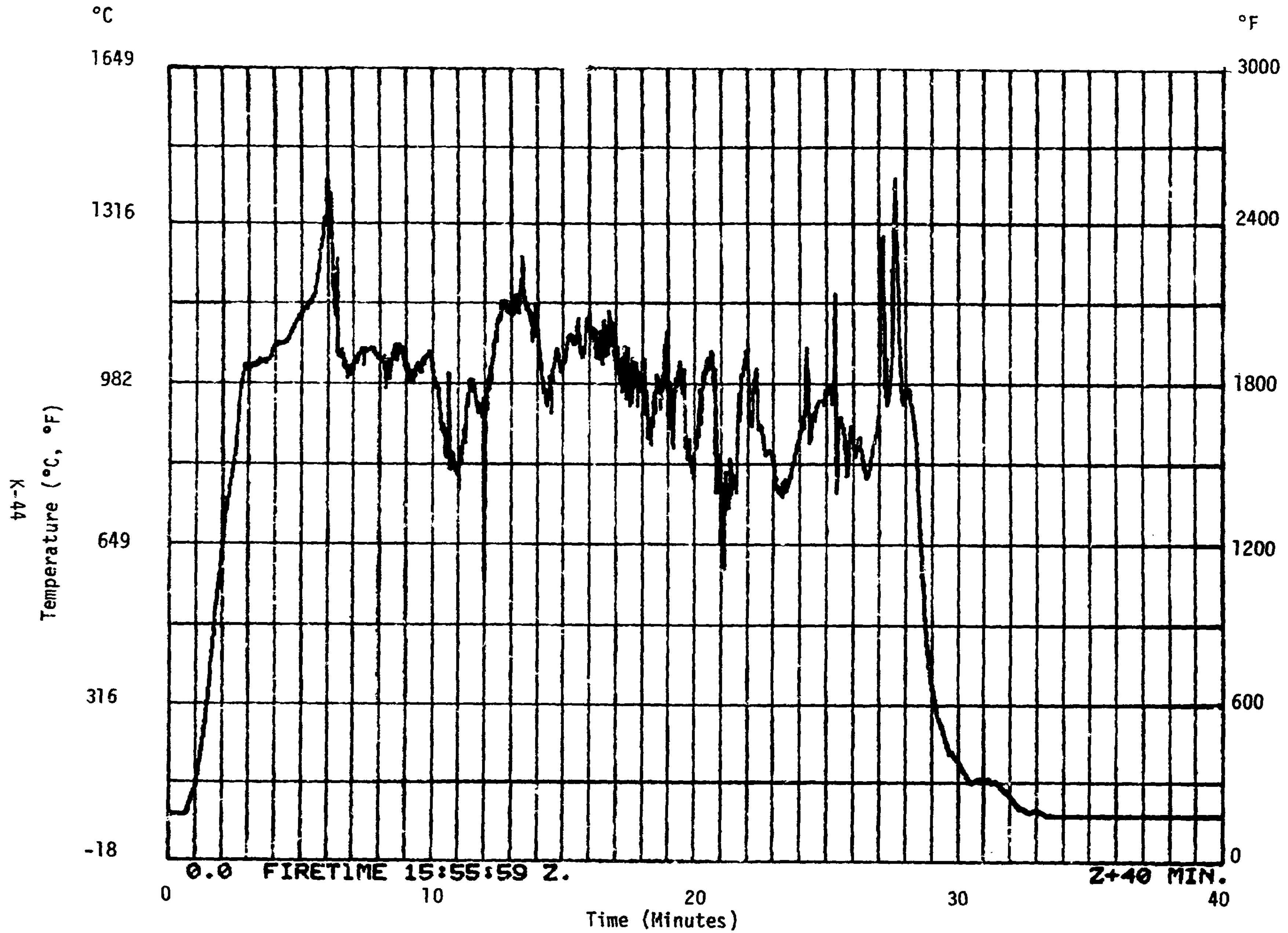
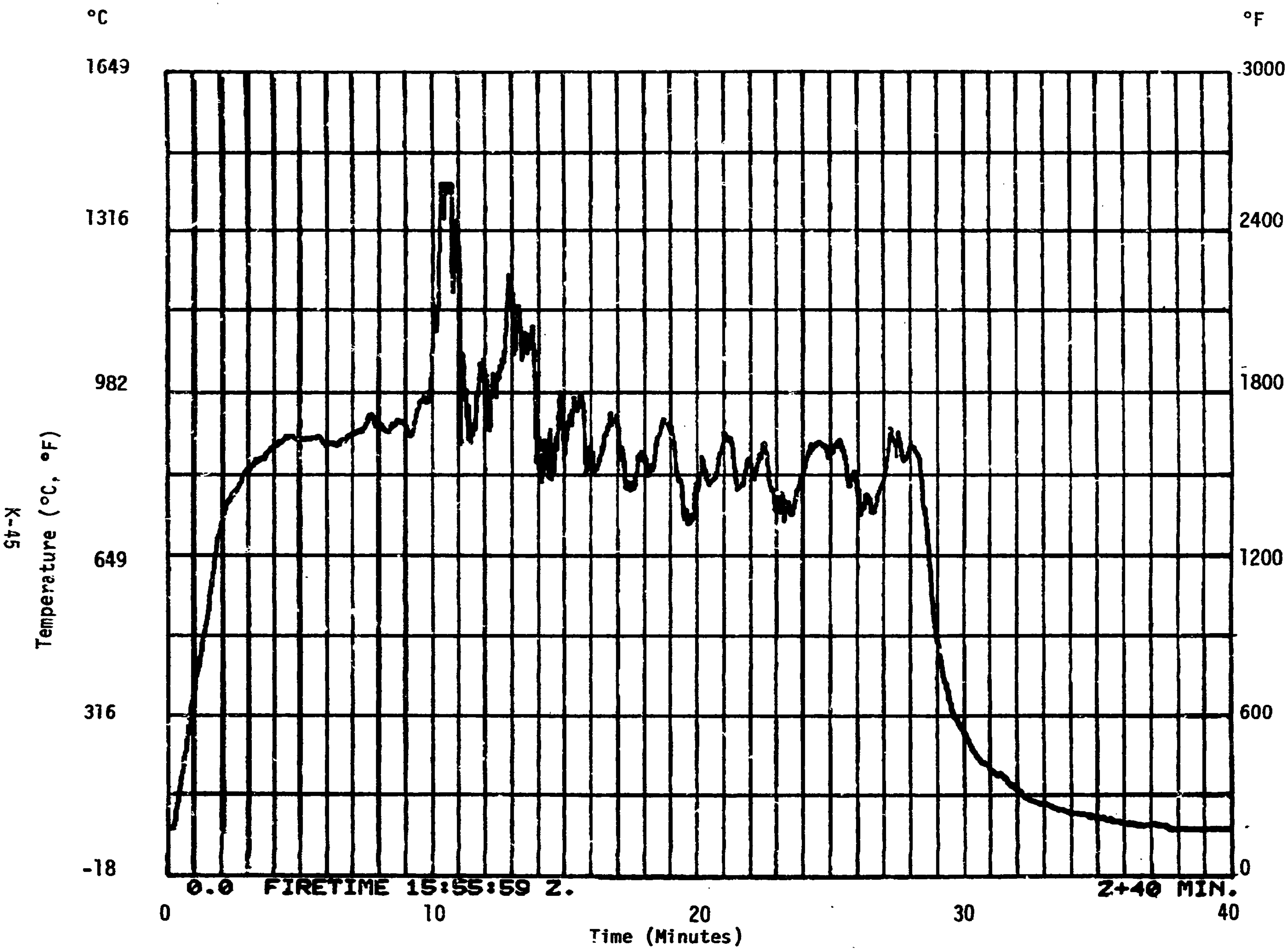


Figure K.39. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial S-1, 15 November 1979, Thermocouple Number 5.


°C
1649
1316
982
649
316
-18
°F
3000
2400
1800
1200
600
0
Temperature (°C, °F)
0.0 FIRETIME 15:55:59 Z.
2+40 MIN.
0
10
20
30
40
Time (Minutes)

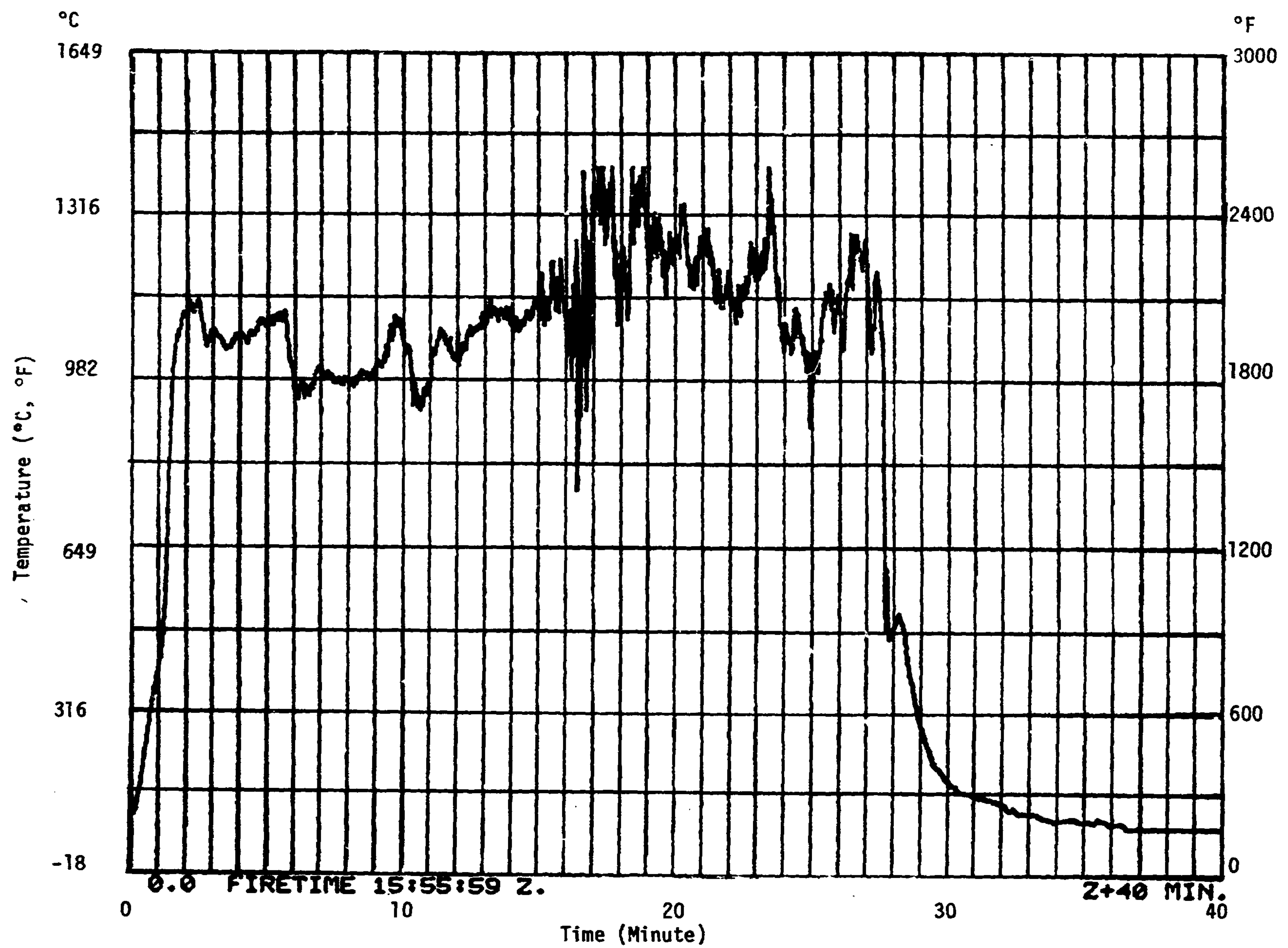


Figure K.41. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial S-1, 15 November 1979, Thermocouple Number 7.

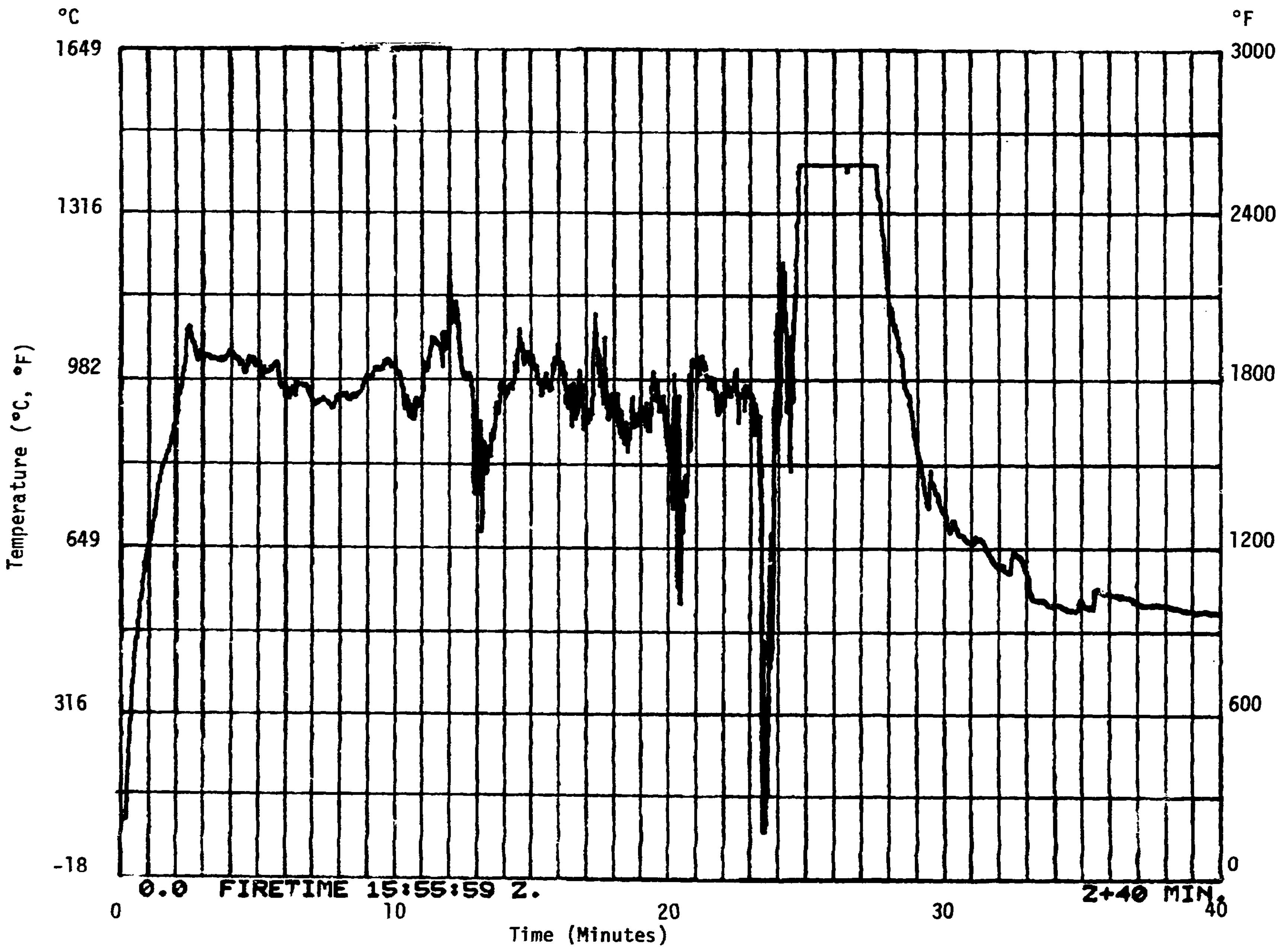


Figure K.42. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial S-1, 15 November 1979, Thermocouple Number 8.

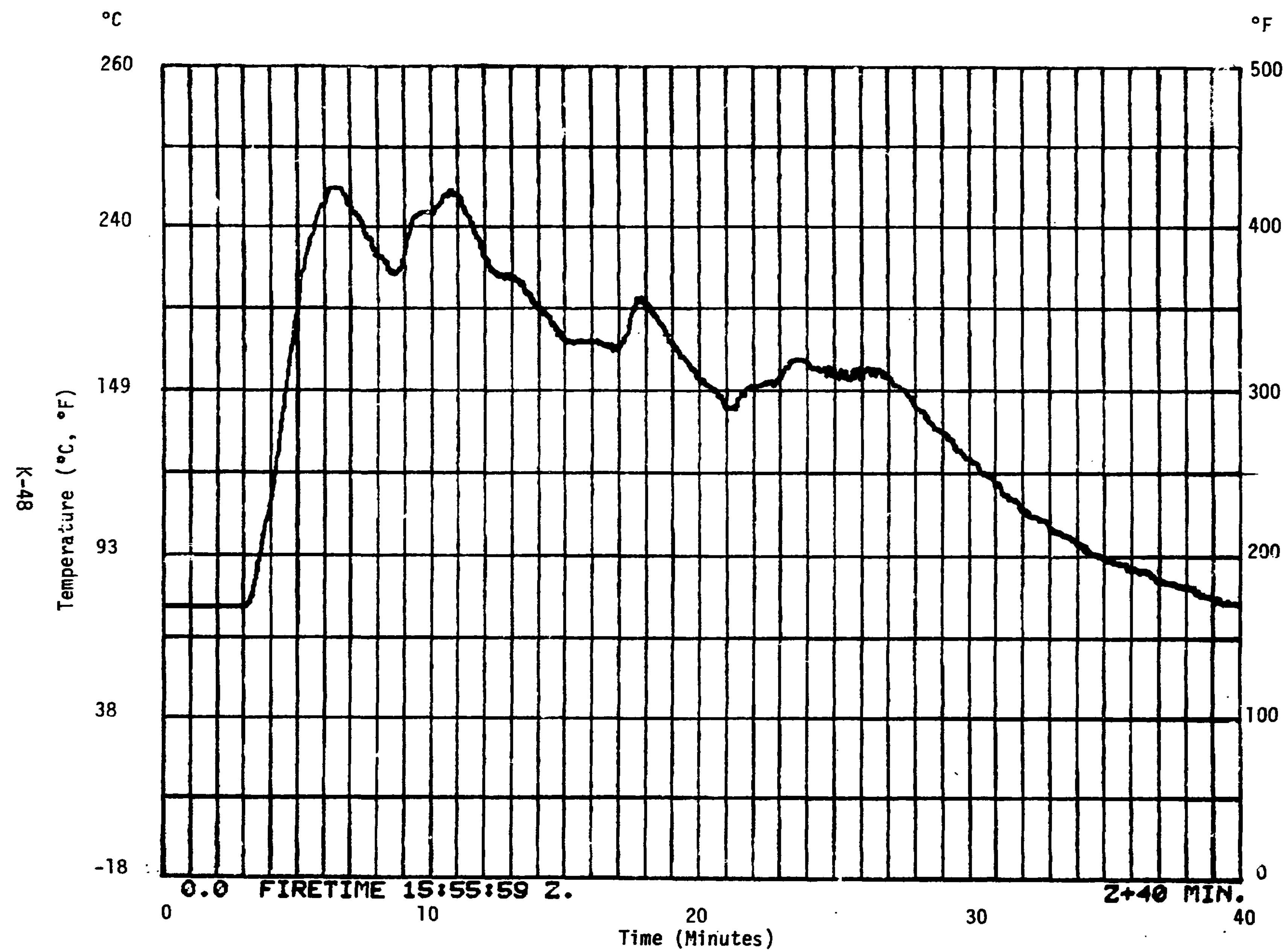


Figure K.43. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial S-1, 15 November 1979, Thermocouple Number 13.

Table K.5. Thermocouple Locations for NASA Carbon Fiber Pool Fire, Trial S-2, 28 November 1979.

Thermocouple Number	Specimen Number	Thermocouple Location
1	S-2-1	Inside speed brake
2	Ambient	In sleeve by speed brake
3	S-2-5	Under specimen
4	Ambient	On top of specimen
5	S-2-1	Inside piece of speed brake
6	Ambient	In sleeve by specimen
7	S-2-3	Inside specimen
8	Ambient	In sleeve by specimen
9	S-2-2	Inside specimen
13	Peterson Sampler	Inside sampler number 12-13
14	Peterson Sampler	Inside sampler number 12-9

NOTE: Thermocouple and specimen location are shown in Figure K.44.

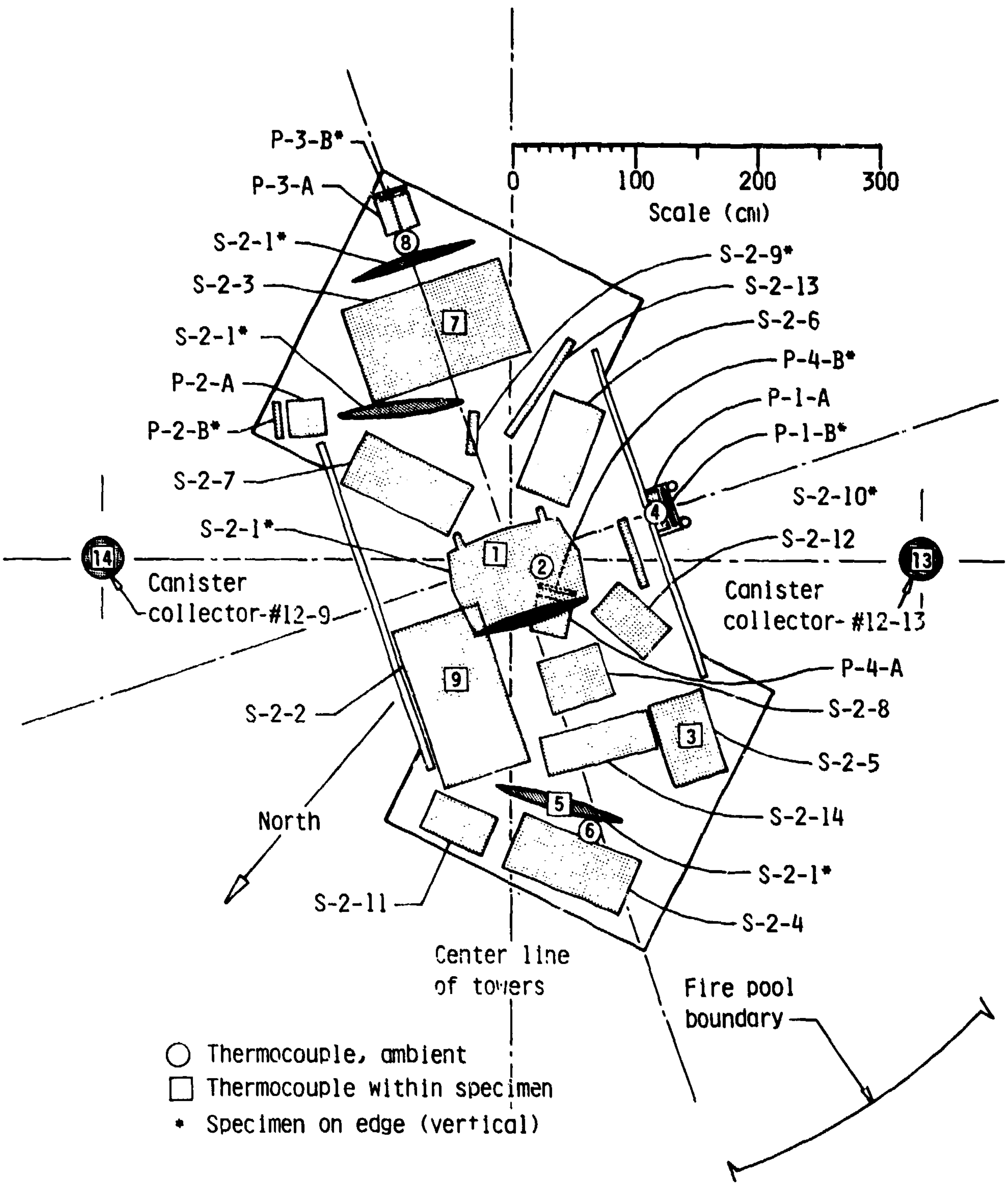


Figure K.44. Thermocouple Locations for Pool Fire S-2, 28 November 1979.

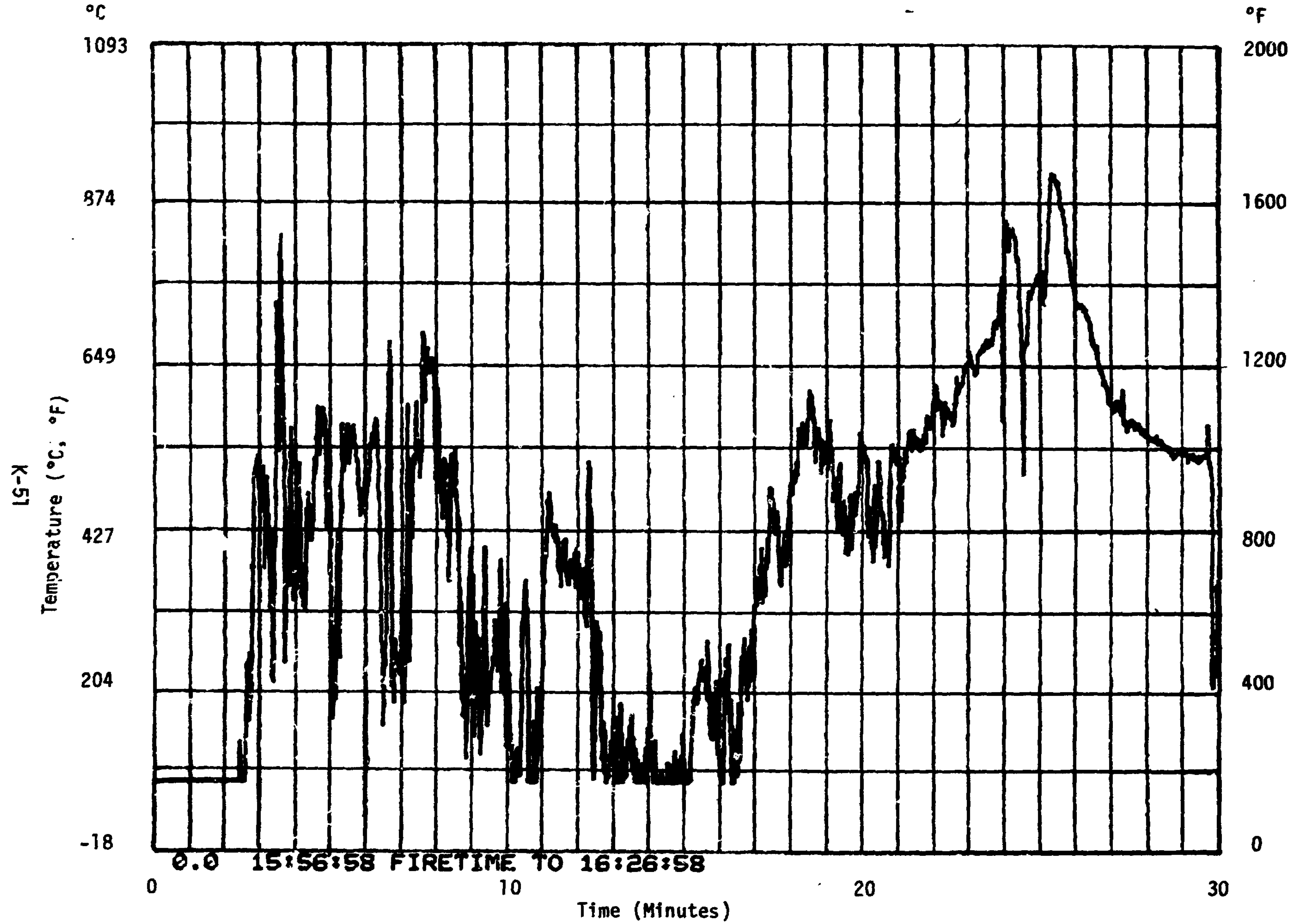


Figure K.45. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial S-2, 28 November 1979, Thermocouple Number 1.

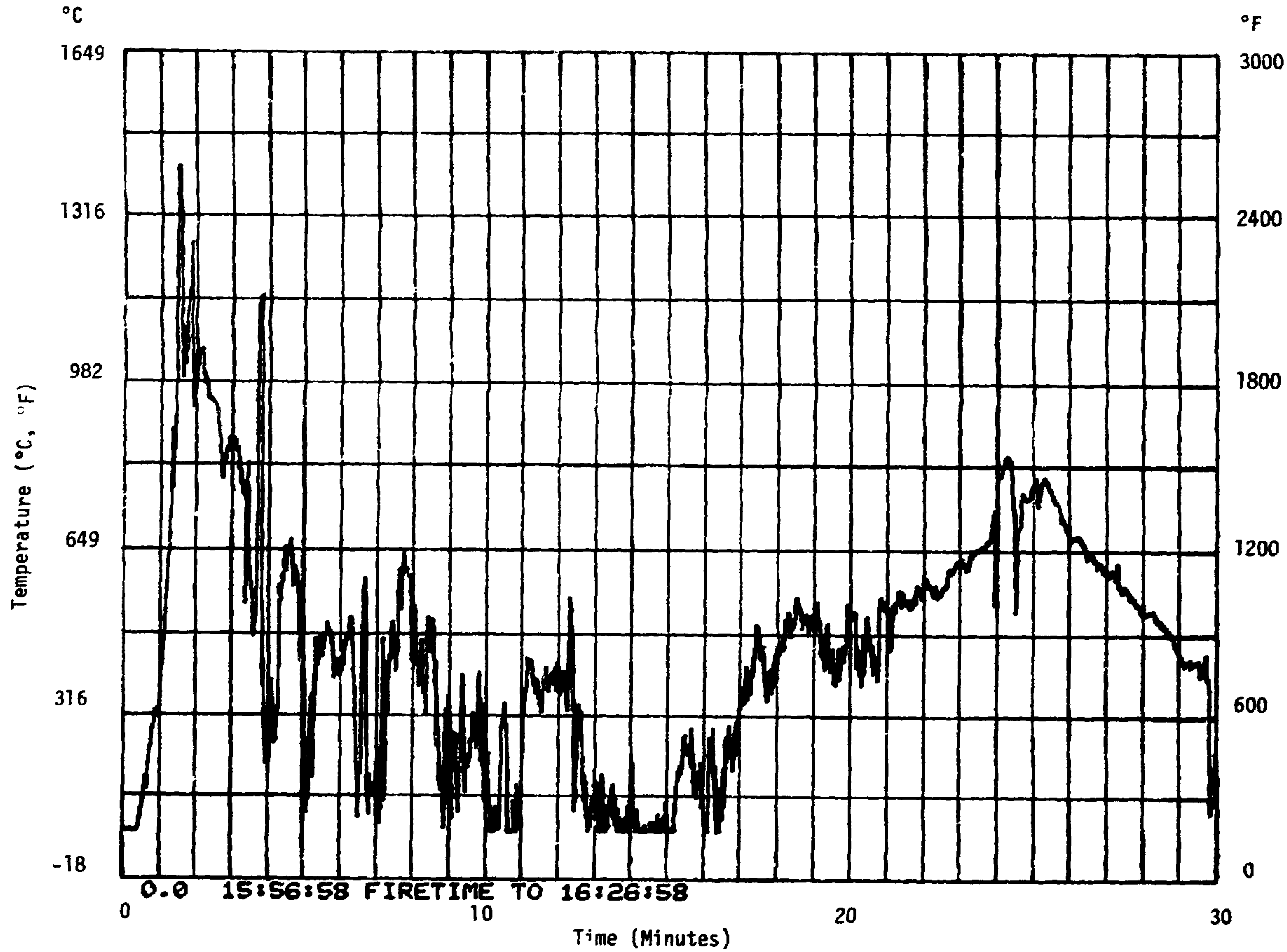


Figure K.46. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial S-2, 28 November 1979, Thermocouple Number 2.

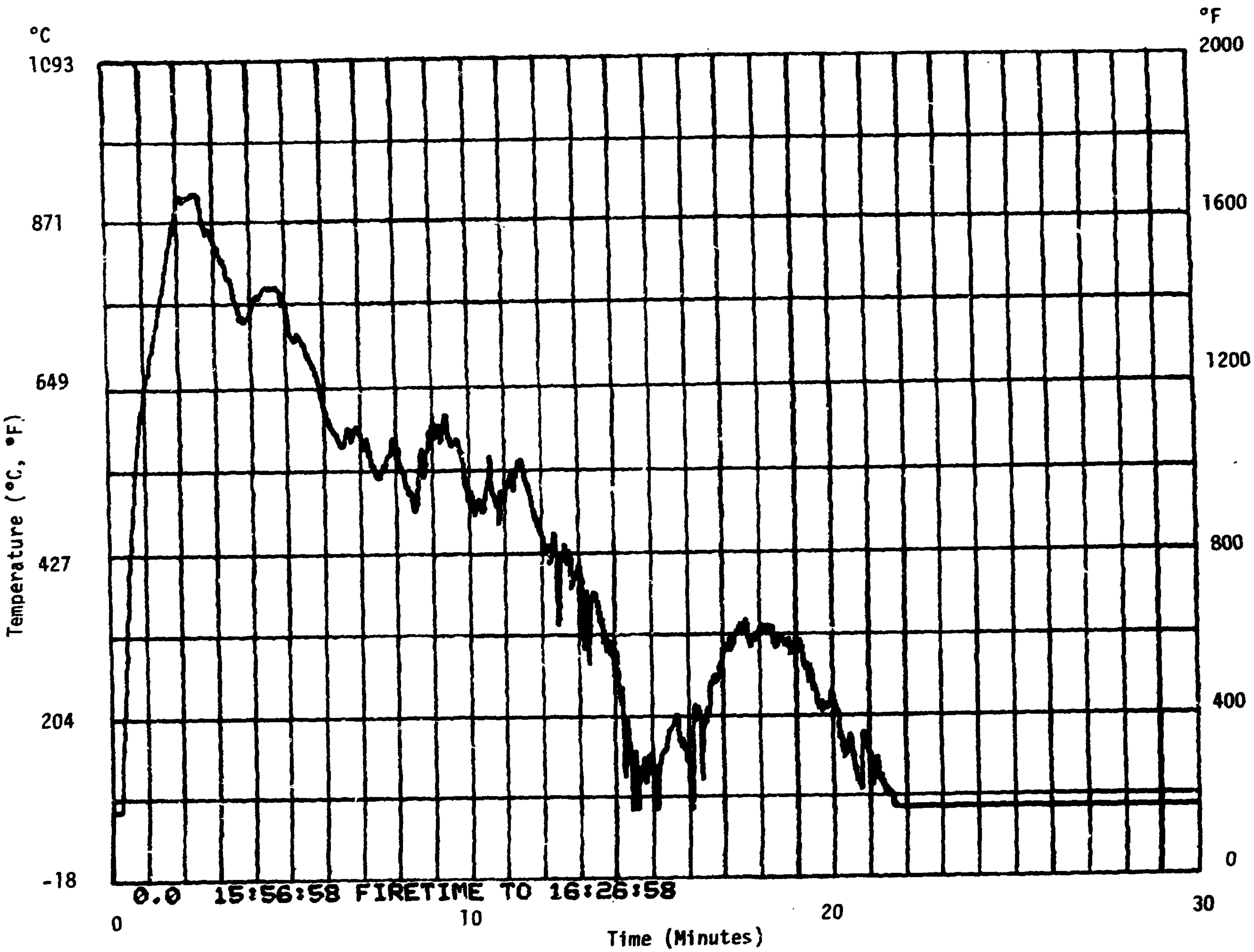


Figure K.47. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial S-2, 28 November 1979,

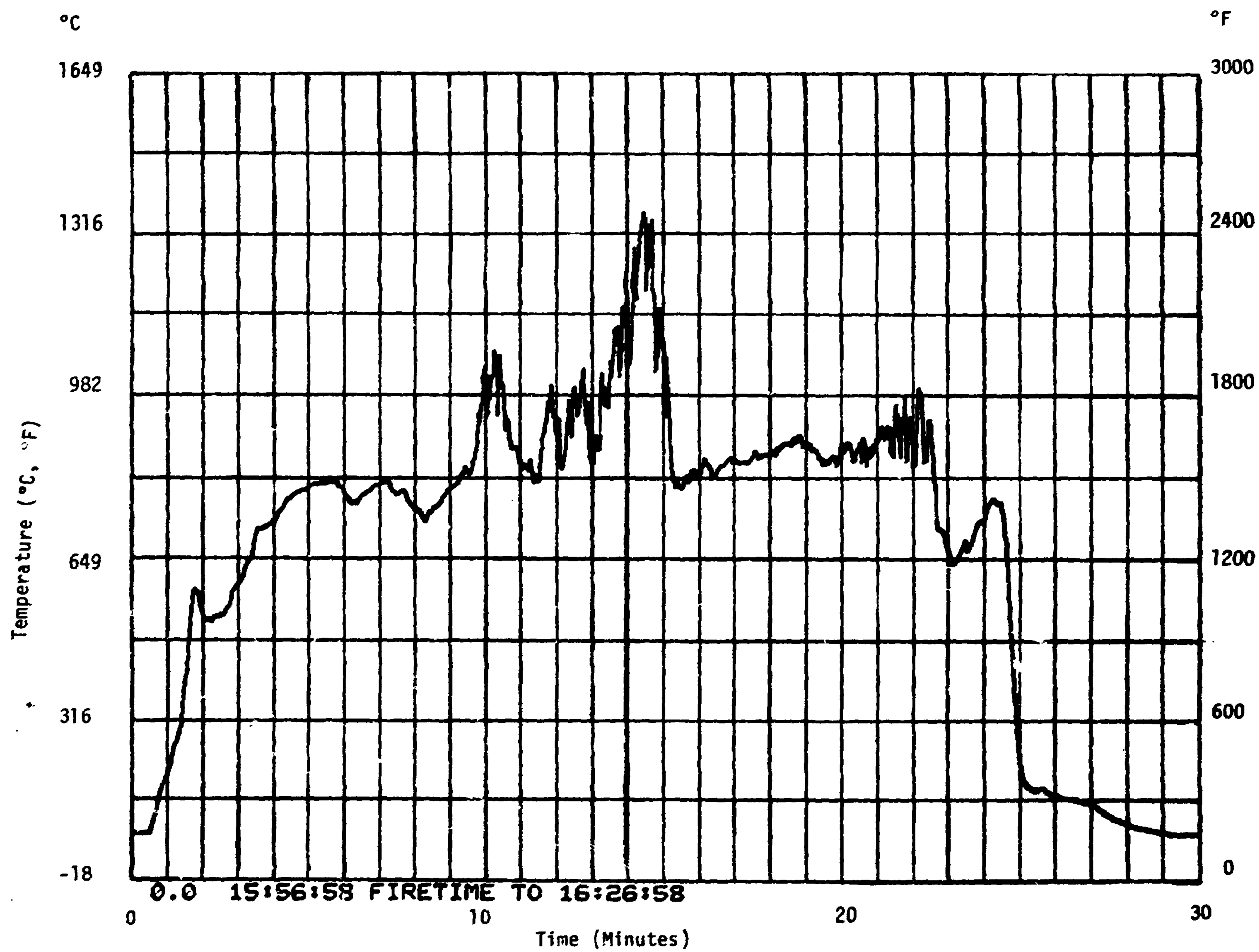


Figure K.48. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial S-2, 28 November 1979, Thermocouple Number 4.

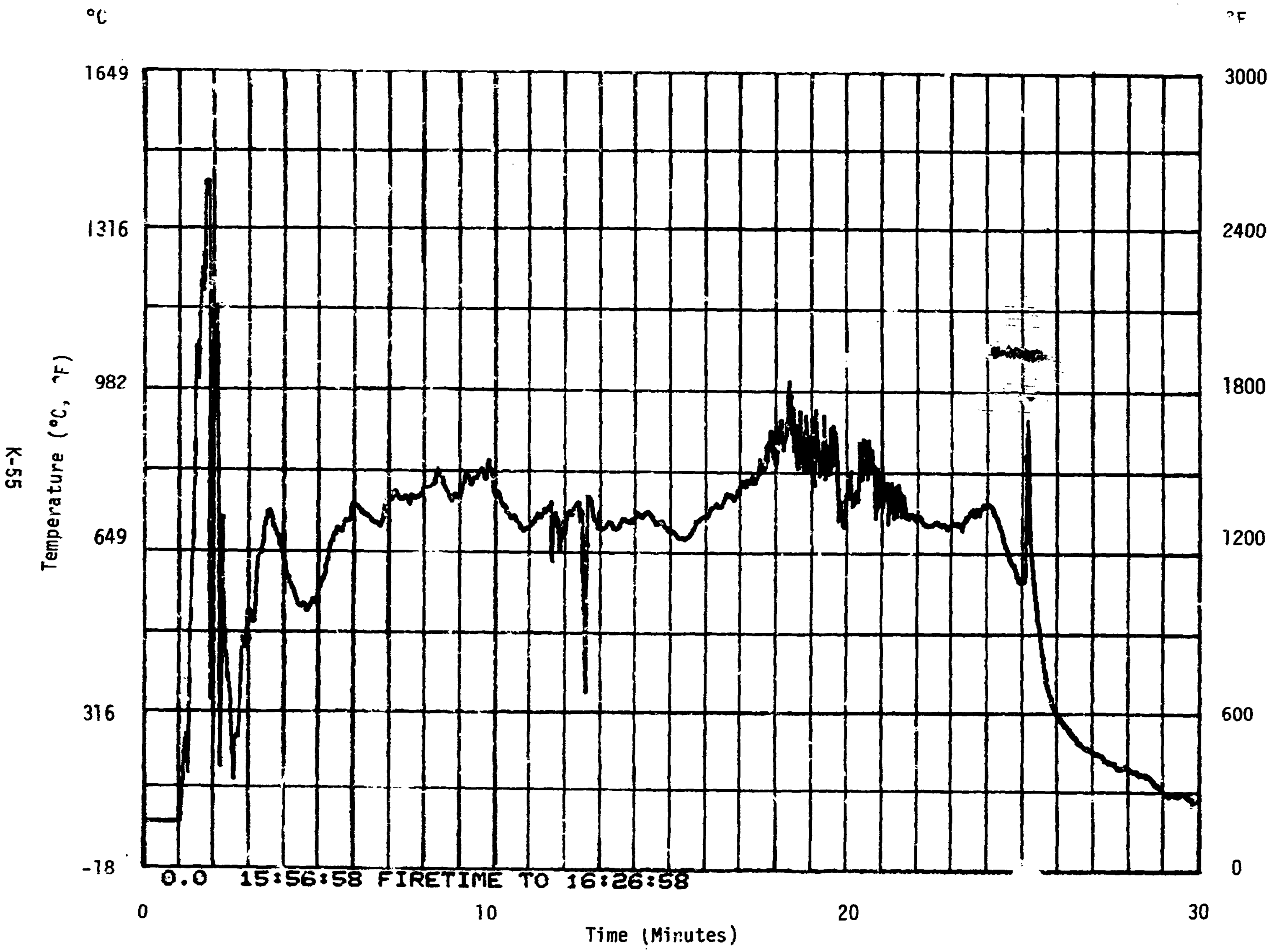


Figure K.49. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial S-2, 28 November 1979, Thermocouple Number 5.

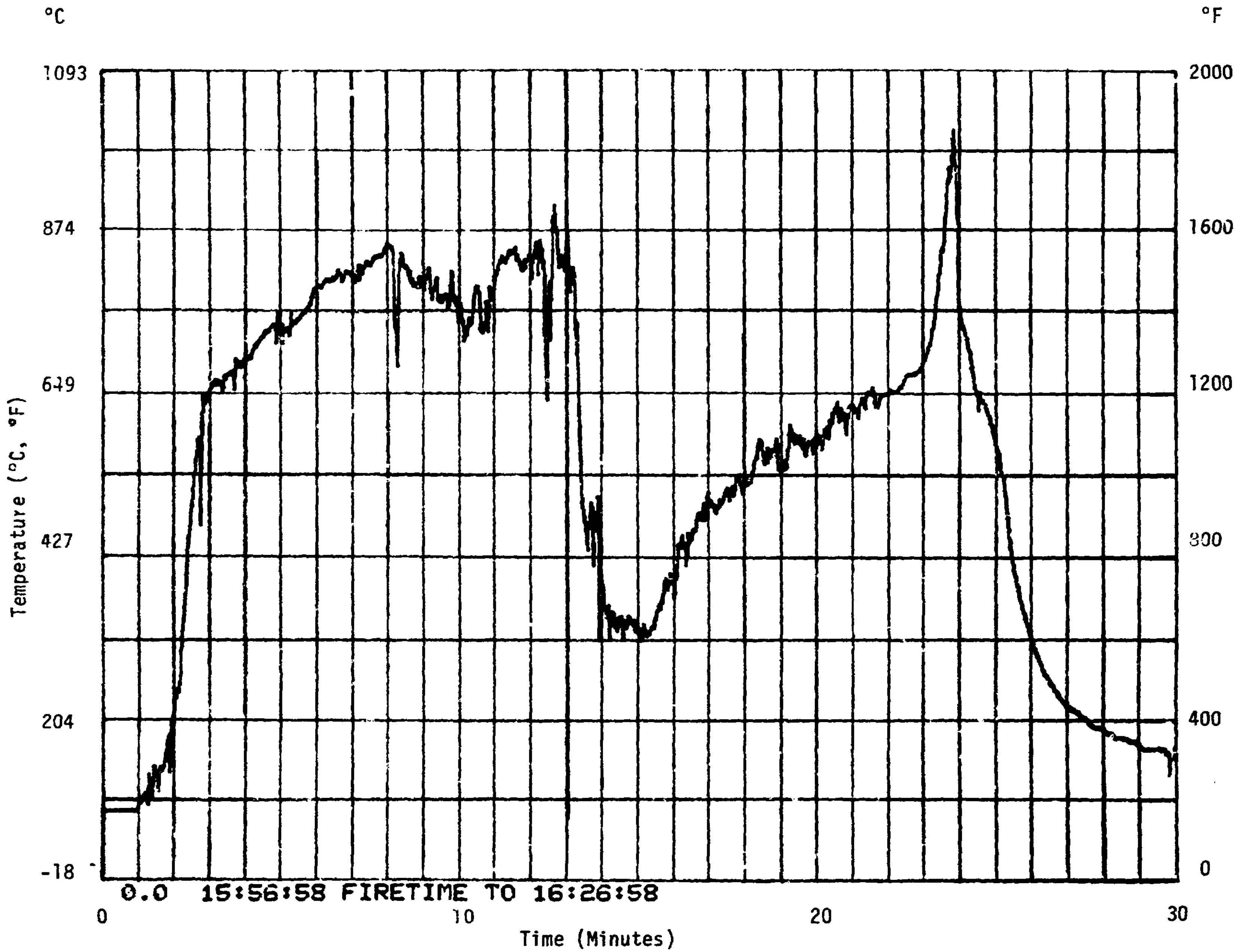


Figure K.50. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial S-2, 28 November 1979, Thermocouple Number 6.

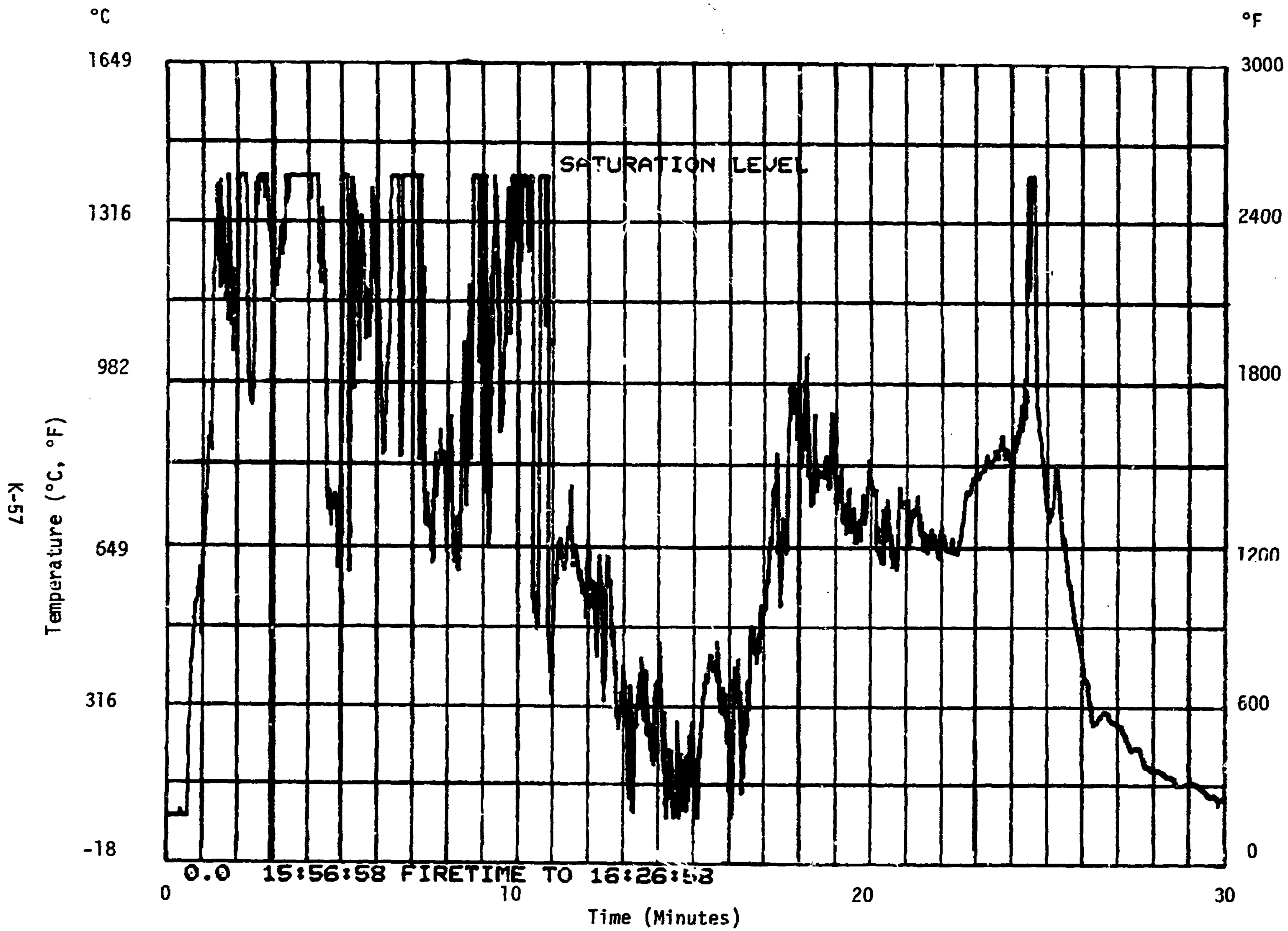


Figure K.51. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial S-2, 28 November 1979, Thermocouple Number 7.

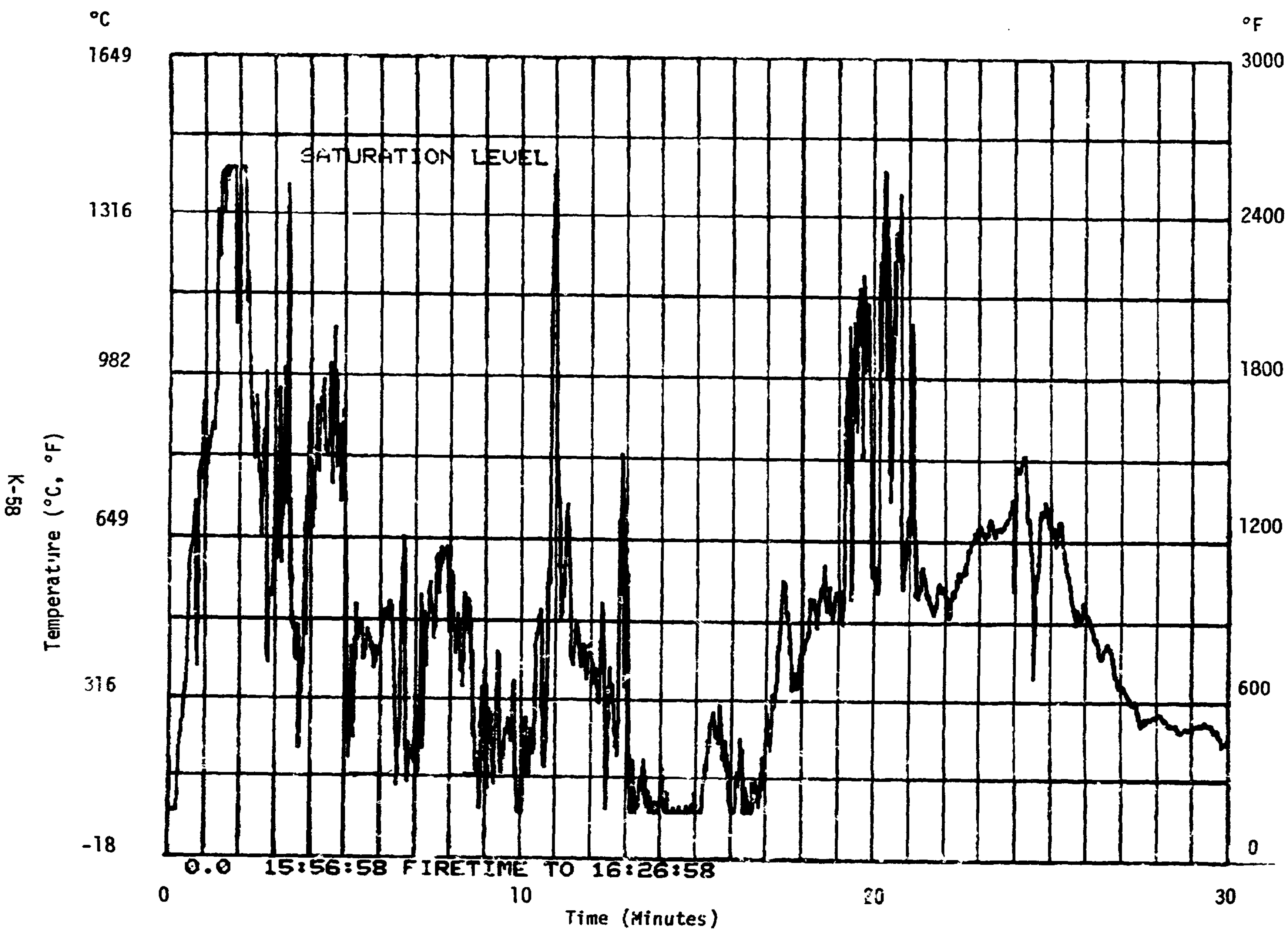


Figure K.52. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial S-2, 28 November 1979, Thermocouple Number 8.

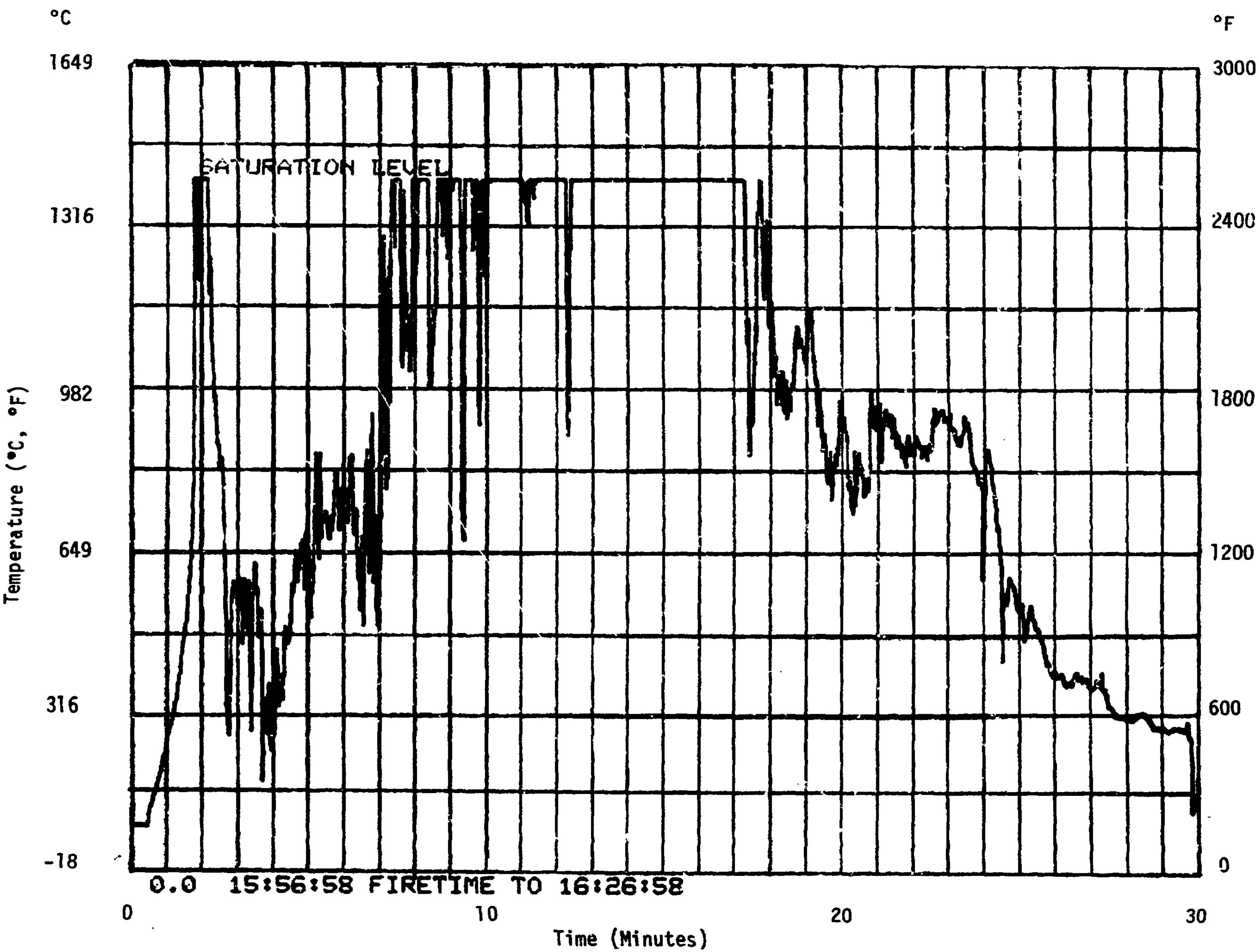


Figure K.53. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial S-2, 28 November 1979, Thermocouple Number 9.

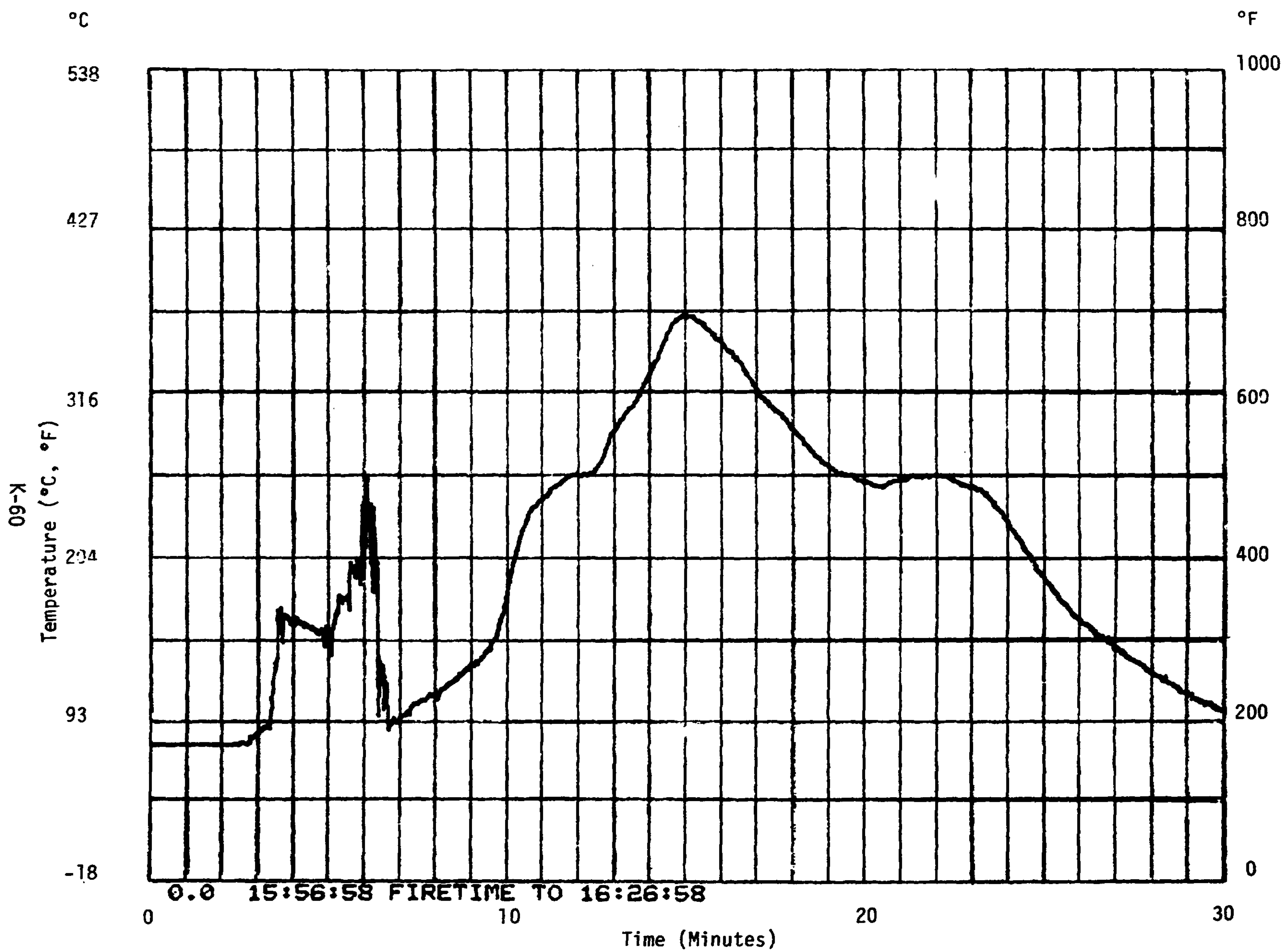


Figure K.54. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial S-2, 28 November 1979, Thermocouple Number 13.

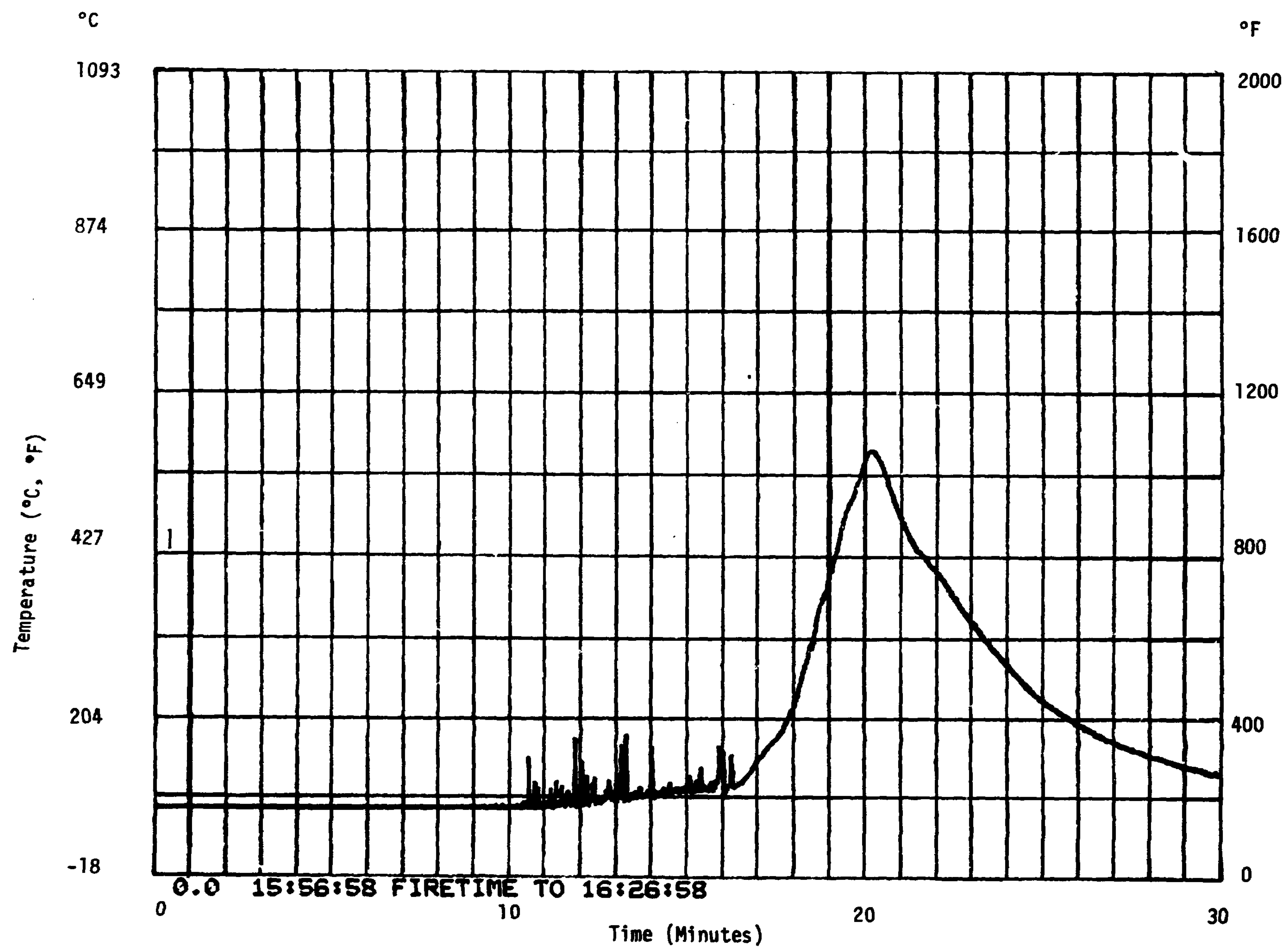


Figure K.55. Temperature Measurements for NASA Carbon Fiber Pool Fire Trial S-2, 28 November 1979, Thermocouple Number 14.

APPENDIX L. AIRCRAFT STRUCTURAL COMPONENTS (MADE OF CARBON FIBERS AND EPOXY) BURNED IN POOL FIRES

NOTE: Specimen locations on the support stand over the fires are shown in figures K.1, K.10, K.20, K.34, and K.44.

Table L.1. Aircraft Structural Components (Made of Carbon Fibers and Epoxy) Burned During Pool Fire Trial D-1, 26 October 1979.

Specimen Number	Description	Nominal Size (cm)	Initial Mass (kg)	Residual Mass (kg)	Lost Mass kg	Lost Mass %	Description of Residue
1 - 1	F-15 speed brake (partial)	141 x 108	13.62[a]	6.90	6.72	49	Severely burned, shape retained
1 - 2	Hat-stiffened panel	109 x 29	1.53	0.02	1.51	99	Severely burned, shape retained
1 - 3	Channel beam	119 x 24	1.62	0	1.62	100	Severely burned, not recovered
1 - 4	DC-10 rudder (partial)	70 x 66	2.27	0.06	2.21	97	Severely burned strips and bits of metal
1 - 5	I-beam	74 x 49	2.27	0.05	2.22	98	Severely burned
1 - 6	Flat plate, with doublers	63 x 49	1.19	0.91	0.28	24	Matrix burned
1 - 7	Flat plate, with doublers	85 x 82	2.47	1.93	0.54	22	Matrix severely burned, strips
1 - 8	Flat plate, woven	62 x 37	1.90	1.59	0.31	16	Matrix burned
1 - 9	Flat plate	61 x 42	0.43	0.43	0	0	Scorched paint
1 - 10	Flat plate, woven and tape	120 x 51	1.76	1.48	0.28	16	Matrix burned
1 - 11	Flat plate, woven	120 x 51	1.84	1.48	0.36	20	Matrix partly burned
1 - 12	Strip stiffened panel	89 x 30	1.79	1.25	0.54	30	Matrix severely burned
1 - 13	Strip stiffened panel	92 x 34	2.27	2.04	0.23	10	Matrix partly burned
1 - 14	Strip stiffened panel	89 x 30	2.24	1.25	0.99	44	Matrix burned
1 - 15	Corrugated web beam, woven	62 x 58	1.28	0.91	0.37	29	Matrix severely burned
1 - 16	Flat panel, with strips	100 x 93	7.72	5.68	2.04	26	Matrix severely burned
TOTAL			46.20	25.98	20.22	44[b]	

[a]Composite
[b]This percentage is for the total amount of composite material not recovered from the support stand during Trial D-1.

Table L.2. Aircraft Structural Components (Made of Carbon Fibers and Epoxy) Burned During Pool Fire Trial D-2, 31 October 1979.

Specimen Number	Description	Nominal Size (cm)	Initial Mass (kg)	Residual Mass (kg)	Lost Mass kg	Lost Mass %	Description of Residue
2 - 1	DC-10 Rudder Section	264 x 72	10.10	0	10.10	100	Completely burned, no residual
2 - 2	Flat plate	86 x 58 x 0.16	1.33	0	1.33	100	Completely burned, no residual
2 - 3	Flat plate	86 x 58 x 0.16	1.31	0	1.31	100	Completely burned, no residual
2 - 4	Stiffened panel, with 4 strips	89 x 30 x 0.32	2.02	0.57	1.45	72	Badly burned, strips only
2 - 5	Stiffened panel, with 4 strips	91 x 30 x 0.32	2.27	1.48	0.79	35	Badly delaminated, matrix burned
2 - 6	DC-10 Rudder, partial piece	43 x 43	1.11	1.08	0.03	2	Surface blistered, one side delaminated
2 - 7	Flat plate sandwich	61 x 36 x 0.80	1.70	0.96	0.74	43	Center burned through, edges delaminated
2 - 8	Stiffened panel, with 3 Hats	84 x 36 x 0.80	3.63	3.06	0.57	16	Stiffeners burned, skin delaminated
2 - 9	Stiffened panel, with 5 Hats	84 x 69 x 0.16	2.72	2.27	0.45	17	Stiffeners and skin delaminated
2 - 10	Stiffened panel, with 3 Hats	84 x 43 x 0.32	2.38	2.30	0.08	3	Partial delamination, matrix partially burned
2 - 11	Corrugated web beam	56 x 50 x 0.16	1.53	1.31	0.22	15	Flange delaminated, matrix partially burned
2 - 12	Corrugated web beam	64 x 50 x 0.10	0.91	0.05	0.86	94	Small pieces of woven materiel
2 - 13	I-beam, with 3 cutouts	79 x 25 x 0.32	1.33	1.25	0.08	6	Flange partially delaminated, matrix partially burned
2 - 14	3 pieces, corrugated web	46 x 36 x 0.16	1.62	1.02	0.60	37	Partial strips, matrix partially burned
2 - 16	Flat plate	76 x 66 x 0.10	1.25	0	1.25	100	Completely burned, no residual
2 - 17	Flat plate	119 x 51 x 0.16	1.48	0.005	1.48	100	Small quantity of delaminated strips
2 - 18	I-beam	48 x 20 x 0.24	0.65	0	0.65	100	Completely burned, no residual
2 - 19	Flat plate, with 1 Hat	81 x 33 x 0.16	1.48	0	1.48	100	Completely burned, no residual
2 - 20	Stiffened panel, with 2 Hats	90 x 32 x 0.64	2.13	0	2.13	100	Completely burned, no residual
2 - 21	Flat sandwich plate	33 x 30 x 0.64	0.44	0	0.44	100	Completely burned, no residual
2 - 22	Stiffened panel, with 2 Hats	91 x 28 x 0.32	1.87	0	1.87	100	Completely burned, no residual
2 - 23	Stiffened panel, with 3 Hats	53 x 41 x 0.32	1.28	0	1.28	100	Completely burned, no residual
2 - 24	Flat plate	91 x 30 x 0.16	0.94	0	0.94	100	Completely burned, no residual
TOTAL			45.48	15.35	30.13	66[a]	

[a]This percentage is for the total amount of composite material not recovered from the support stand during Trial D-2.

Table L.3. Aircraft Structural Components (Made of Carbon Fibers and Epoxy), F-16 Tail, Burned During Pool Fire Trial D-3, 9 November 1979.

Specimen Number	Description	Nominal Size (cm)	Initial Mass (kg)	Residual Mass (kg)	Lost Mass kg	Lost Mass %	Description of Residue
3-LV & 3-RV	Two Vertical Stabilizer Skins	292 x 106	45.40	18.95	26.45	58	Severely burned, strips and plies
3-LH	Left Hoizontal Stabilizer W/ Titanium Fittings & Aluminum Honeycomb	76 x 190	44.04	33.88			
	Composite Skins, only		11.33	8.80	2.53	22	Severely burned, thick part of laminate retained by rivets
3-RH	Right Horizontal Stabilizer W/ Titanium Fittings & Aluminum Honeycomb	169 x 185	50.85	35.07			
	Composite Skins, only		14.04	9.03	5.01	36	Severely burned, thick part of laminate retained by rivets
TOTAL			70.77	36.78	33.99	48[a]	

[a]This percentage is for the total amount of composite material not recovered from the support stand during Trial D-3.

Table L.4. Aircraft Structural Components (Made of Carbon Fibers and Expoxy) Burned During Pool Fire Trial S-1, 15 November 1979.

Specimen Number	Description	Nominal Size (cm)	Initial Mass (kg)		Residual Mass (kg)		Lost Mass kg		Lost Mass %		Description of Residue
3 - 1	F-15 speed brake	246 x 108	19.52[a]		8.80		10.72		55		Severely burned, strips and plates
3 - 2	Heavy Spar	113 x 36	8.00		3.91		4.09		51		Severely burned and delaminated
3 - 9	Corrugated web beam, woven	66 x 56	1.76		0.79		0.97		55		Severly burned and delaminated
3 - 3	I-stiffened panel	130 x 46	2.38		-		-		-		
3 - 4	Strip-stiffened panel	58 x 33	1.05		-		-		-		
3 - 5	D-10 rudder, partial	36 x 36	3.68		-		-		-		Specimens 3 - 3 through 3 - 8 and 3 - 10 through 3 - 11C severely burned, identification of individual items not possible
3 - 6	I-stiffened panel	117 x 46	2.04		-		-		-		
3 - 7	I-stiffened panel	112 x 46	1.93		-		-		-		
3 - 8	I -stiffened panel	91 x 46	1.59	19.3[a]	-	2.39[b]	-	16.91[b]	-	88[b]	
3 - 10	Panel with honeycomb stiffeners	81 x 37	3.75		-		-		-		
3 - 11A	Honeycomb sandwich panel	152 x 71	2.50		-		-		-		
3 - 11B	Honeycomb sandwich panel	152 x 71	2.50		-		-		-		
3 - 11C	J-section stiffener	112 x 110	0.68		-		-		-		
TOTAL			48.56		15.89		32.69		67[c]		

[a]Composite
[b]Individual specimen identity not possible, items severely burned.
[c]This percentage is for the total amount of composite material not recovered from the support stand during Trial S-1.

Table L.5. Aircraft Structural Components (Made of Carbon Fibers and Epoxy) Burned During Pool Fire Trial S-2, 28 November 1979.

Specimen Number	Description	Nominal Size (cm)	Initial Mass (kg)	Residual Mass (kg)	Lost Mass kg	Lost Mass %	Description of Residue
S-2-1	F-15 Speed brake, 4 pieces	246 x 108	19.07[a]	11.69	7.38	39	Severely burned and delaminated; some clamp-up attachment to metal parts. Excessive sooting on back of speed brake
S-2-2	Honeycomb Sandwich Panel	135 x 81	2.38				
S-2-3	Honeycomb Sandwich Panel	135 x 81	2.38				
S-2-4	I-stiffened Panel	102 x 48	1.79				
S-2-5	I-stiffened Panel	71 x 46	1.28				
S-2-6	I stiffened Panel	86 x 47	1.31				
S-2-7	I-steffened Panel	98 x [illegible]	1.39				
S-2-8	Corrugated Web	53 x 51	0.74				
S-2-9	DC-10 Rudder Piece	29 x 23	0.23				
S-2-10	Hat-stiffened Panel	57 x 34	0.85				
S-2-11	Hat-stiffened Panel	57 x 35	0.85				
S-2-12	Hat-stiffened Panel	57 x 34	0.82				
S-2-13	Strip-stiffened Panel	92 x 35	2.30				Individual specimen identity was not maintained in residue recovery. All residue severely burned.
S-2-14	Strip-stiffened Panel	92 x 33	2.32				
	Totals for Specimens 2 through 14		18.64	10.90	7.74	41	
P1A	Flat Plate, horizontal	30 x 30 x 0.80	1.1072	0.7557	0.3515	32	All plates severely burned and delaminated, shape retained; horizontal plates not as damaged due to steel grill support underneath.
P1B	Flat Plate, vertical	30 x 30 x 0.79	1.1028	0.6400	0.4628	42	
P2A	Flat Plate, horizontal	30 x 30 x 0.80	1.1100	0.5752	0.5349	48	
P2B	Flat Plate, vertical	30 x 30 x 0.80	1.1128	0.5726	0.5402	49	
P3A	Flat Plate, horizontal	30 x 30 x 0.62	0.8580	0.3997	0.4583	53	
P3B	Flat Plate, vertical	30 x 30 x 0.60	0.8399	0.2652	0.5747	68	
P4A	Flat Plate, horizontal	30 x 30 x 0.61	0.8502	0.4960	0.3542	42	
P4B	Flat Plate, vertical	30 x 30 x 0.61	0.8546	0.4222	0.4324	51	
TOTAL			45.55	26.72	18.83	41[b]	

[a]Composite weight

[b]This percentage is for the total amount of composite material not recovered from the support stand during Trial S-2.

APPENDIX M. PICTORIAL RECORD OF TEST SITE PREPARATION

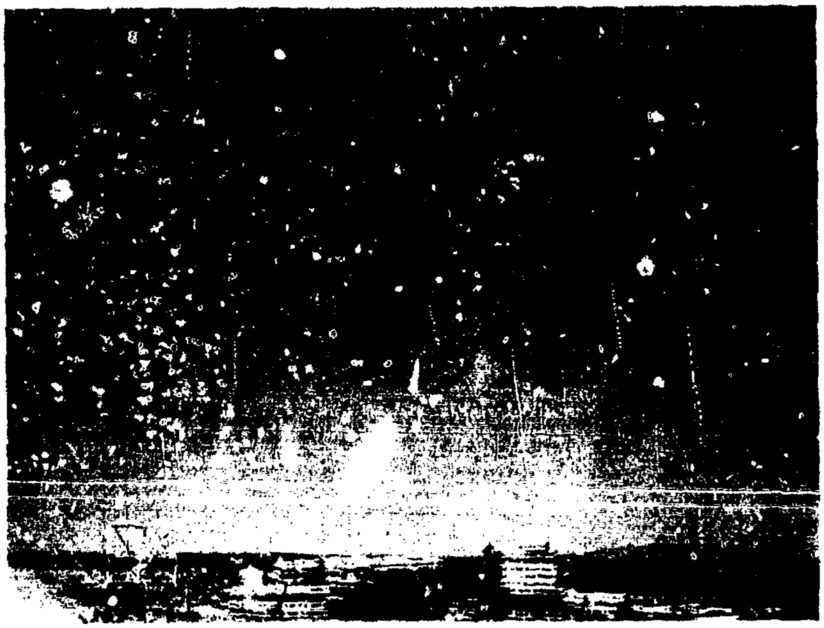


Figure M.1. Beginning of Tower Erection for Carbon Fiber Pool Fire Test.

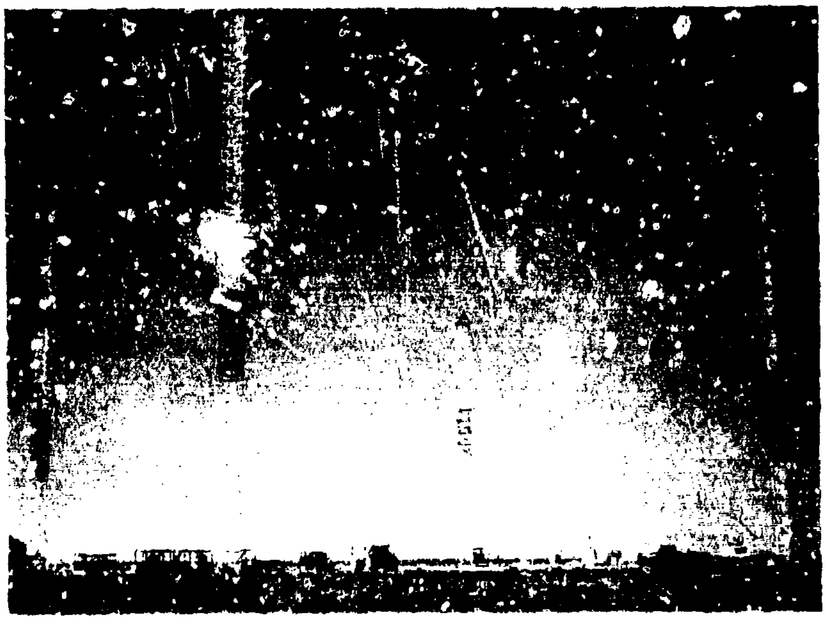


Figure M.2. Tower Erection 90 Percent Comple-- for Carbon Fiber Pool Fire Test.

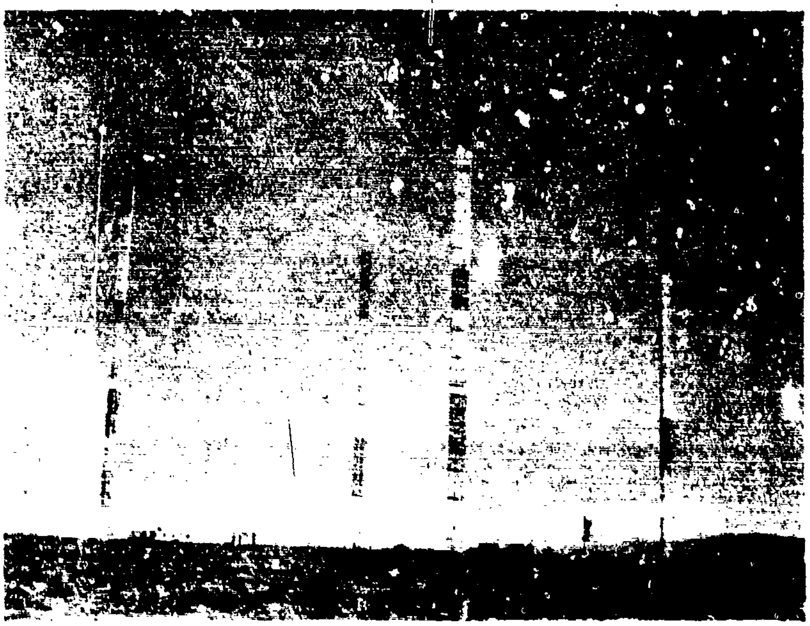


Figure M.3. Tower Erection 100 Percent Complete for Carbon Fiber Pool Fire Test.

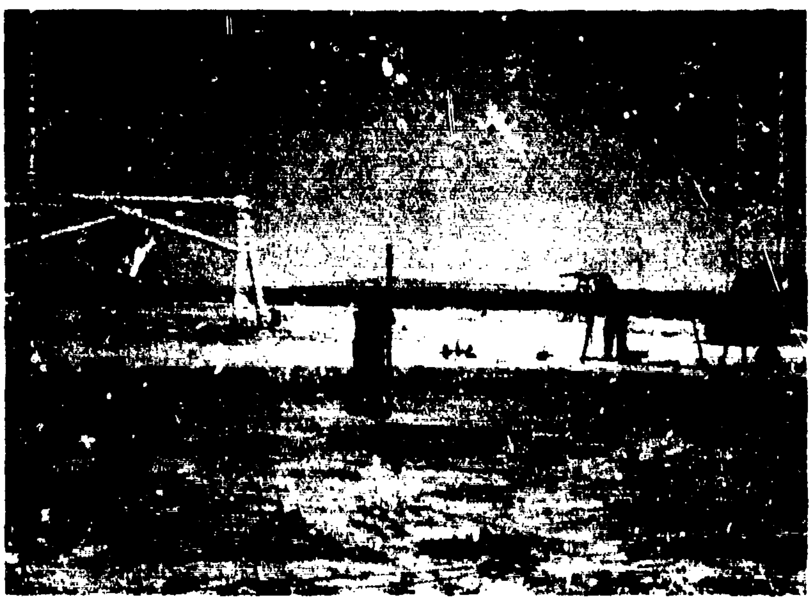


Figure M.4. Final Grades for South Pit Excavation, Carbon Fiber Pool Fire Test.

Figure M.5. Final Preparation Prior to Pouring Concrete in South Pit, Carbon Fiber Pool Fire Test.

Figure M.6. Preparing Ground for Concrete in South Pit, Carbon Fiber Pool Fire Test.

Figure M.7. Pouring Concrete in South Pit for Carbon Fiber Pool Fire Test.

Figure M.8. Completed Burn Pits for Carbon Fiber Pool Fire Tests.

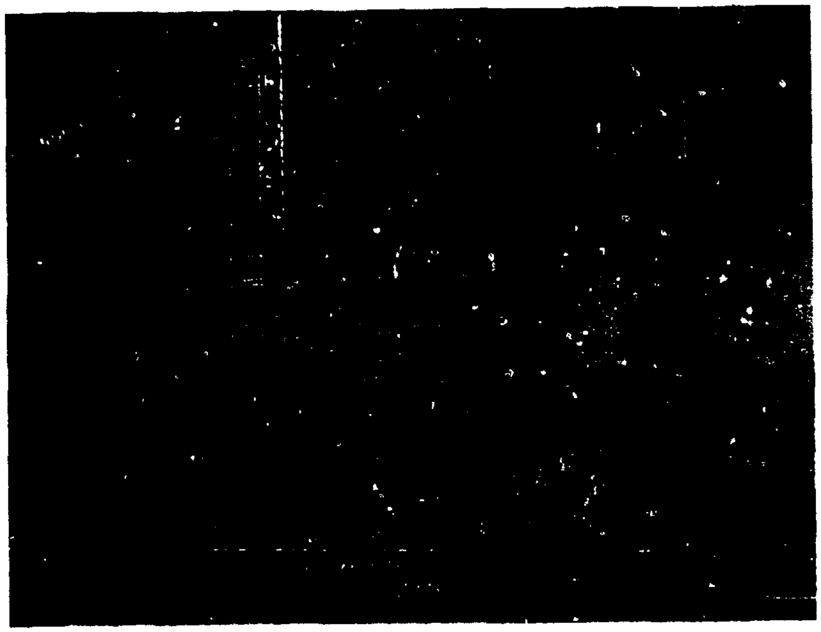


Figure M.9. Installation of Vertical Sampling Brackets, Carbon Fiber Pool Fire Tests.

Figure M.10. Excavation for Jacob's Ladder Anchors, Carbon Fiber Pool Fire Tests.

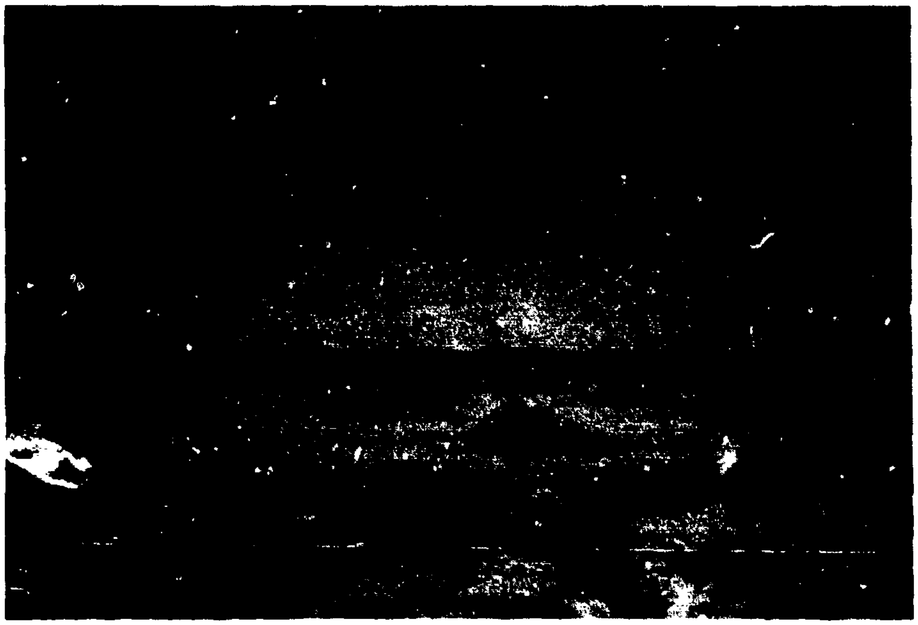


Figure M.11. Excavated Anchor Holes at the Aft Tether Position for Jacob's Ladder, Carbon Fiber Pool Fire Test.

Figure M.12. Anchor Rod Positioned in Anchor Hole for Jacob's Ladder, Carbon Fiber Pool Fire Test.

Figure M.13. Pouring Anchors for Jacob's Ladder, Carbon Fiber Pool Fire Test.

Figure M.14. Finished Anchors for Jacob's Ladder, Carbon Fiber Pool Fire Test.

Figure M.15. Load Testing of Anchors for Carbon Fiber Pool Fire Test.

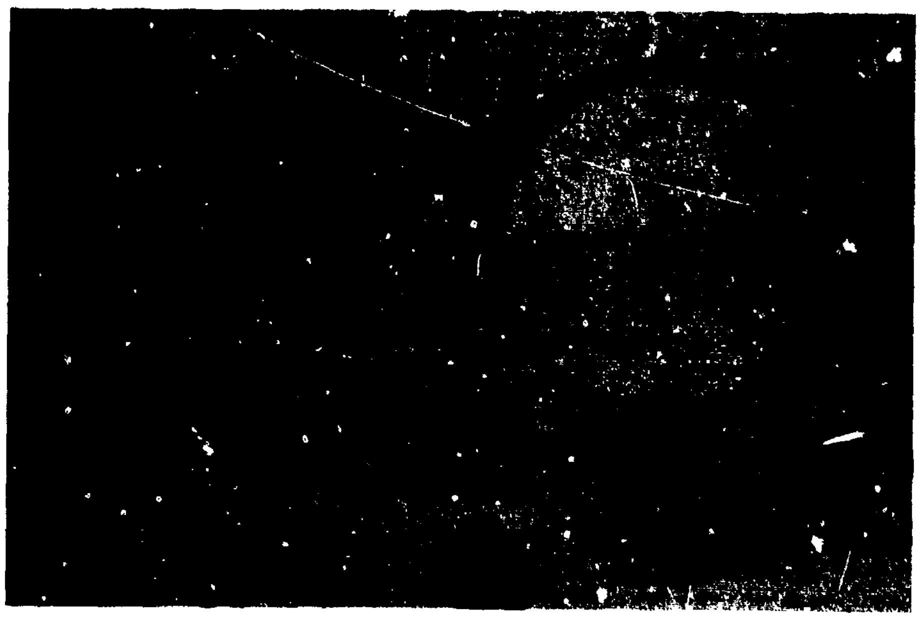


Figure M.16. Load Tester.

Figure M.17. Jacob's Ladder Stabilizing Position for Carbon Fiber Pool Fire Test.

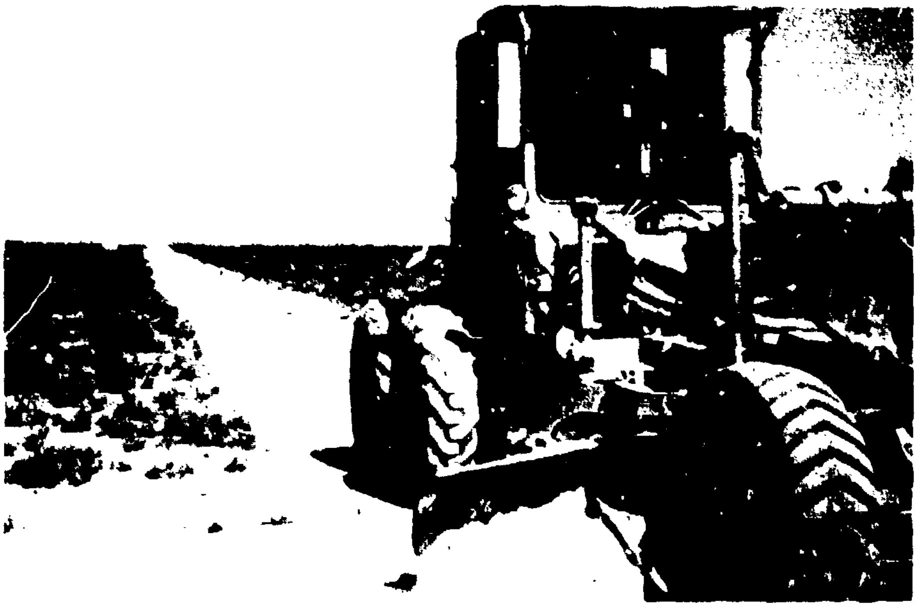


Figure M.18. Grading Paths for Jacob's Ladder Tether Lines, Carbon Fiber Pool Fire Tests.

Figure M.19. Corner Post for Jacob's Ladder Apron, Carbon Fiber Pool Fire Test.

Figure M.20. Laying Out Jacob's Ladder for Carbon Fiber Pool Fire Test.

Figure M.21. Splicing End Fittings for Jacob's Ladder, Carbon Fiber Pool Fire Tests.

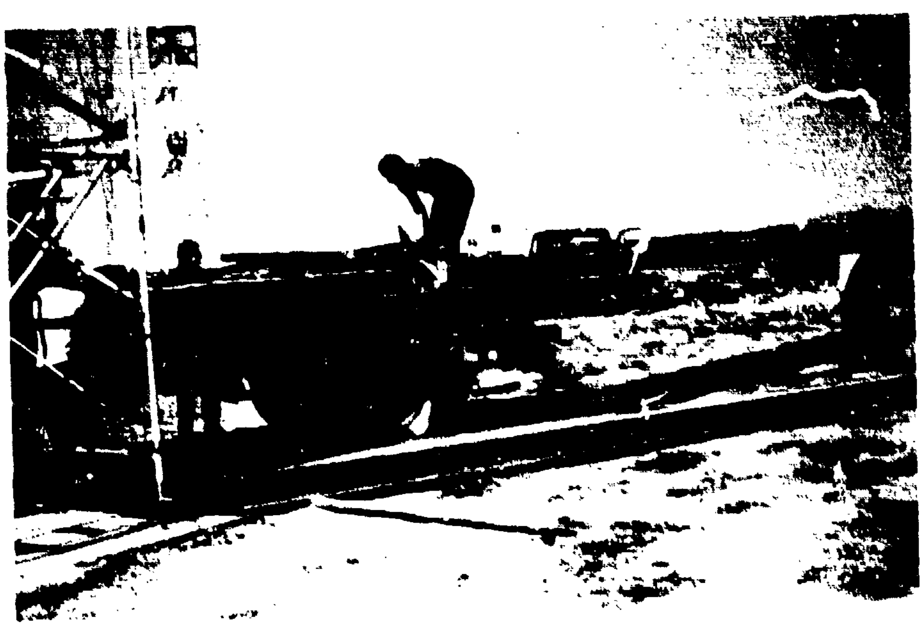


Figure M.22. Unloading I-Beams for Canopy Array at Grid Site, Carbon Fiber Pool Fire Tests.

Figure M.23. Attaching Supports to I-Beams for Canopy Array, Carbon Fiber Pool Fire Tests.

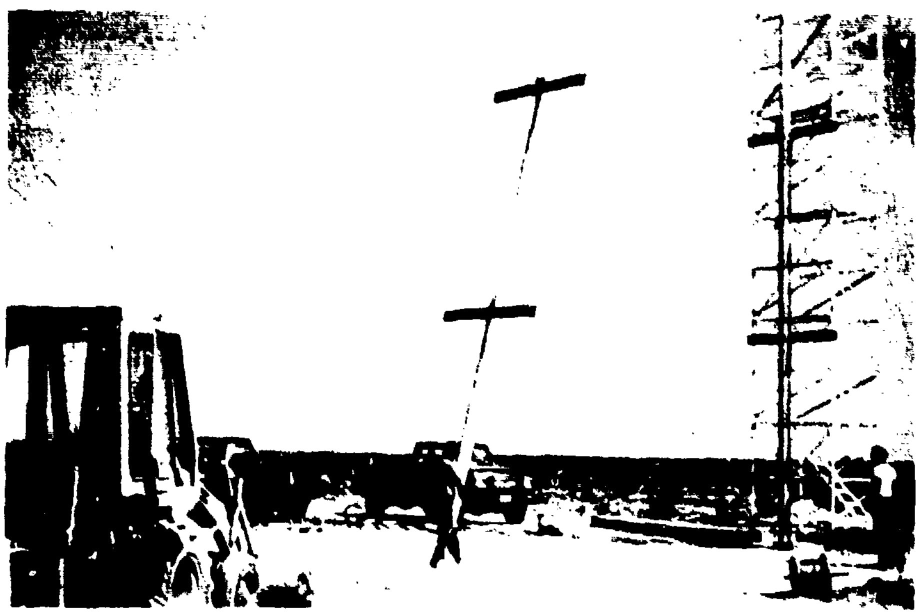


Figure M.24. Raising I-Beam for Installation on Tower to Support Overhead Cable Canopy Array, Carbon Fiber Pool Fire Tests.

Figure M.25. Raising I-Beam for Installation of Tower to Support Overhead Canopy Hoisting Trolley, Carbon Fiber Pool Fire Tests.

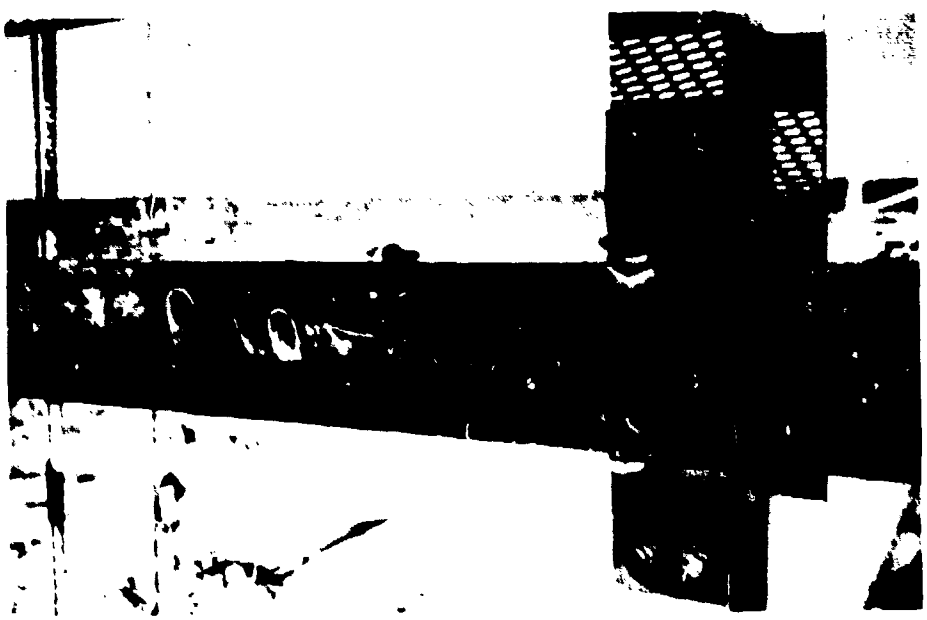


Figure M.26. Supports for I-Beams on Overhead Canopy Array, Carbon Fiber Pool Fire Tests.

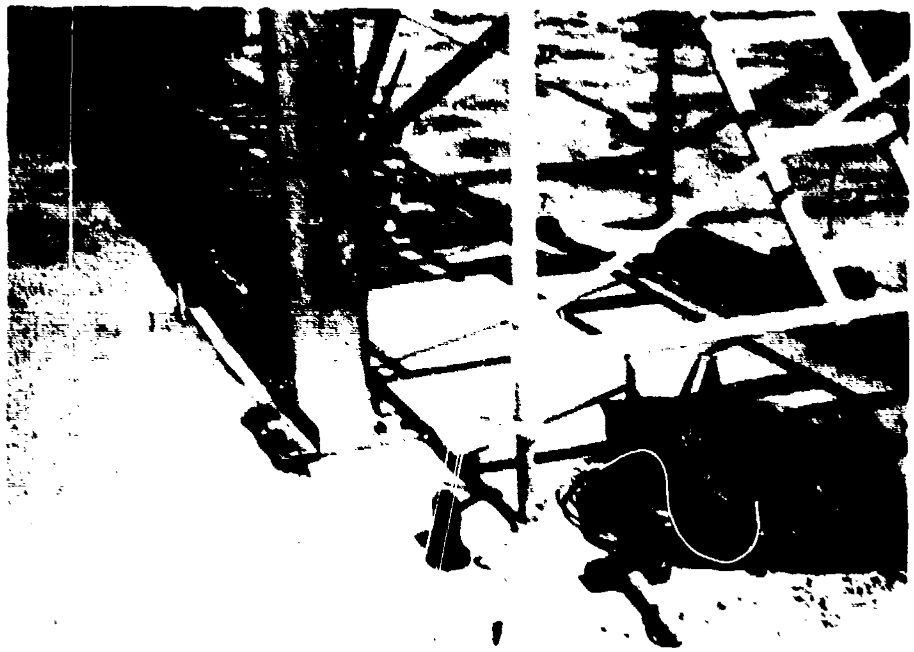


Figure M.27. Base Support for I-Beam of Overhead Caropy Array, Carbon Fiber Pool Fire Tests.

APPENDIX N. PICTORIAL DISPLAY OF TYPICAL TRIAL OPERATIONS AND SUPPORT ELEMENTS

Figure N.1. Pumping JP-4 into Burn Pit.

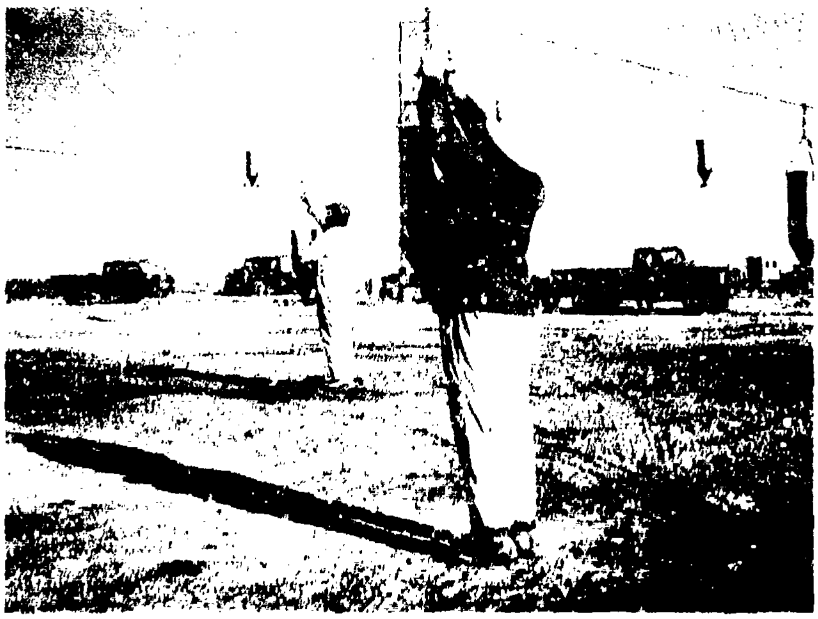


Figure N.2. Sampler Setup Prior to Carbon Fiber Pool Fire Test.

Figure N.3. Collecting Wire Mesh Samplers After Source/Dissemination Trial, Carbon Fiber Pool Fire Test.

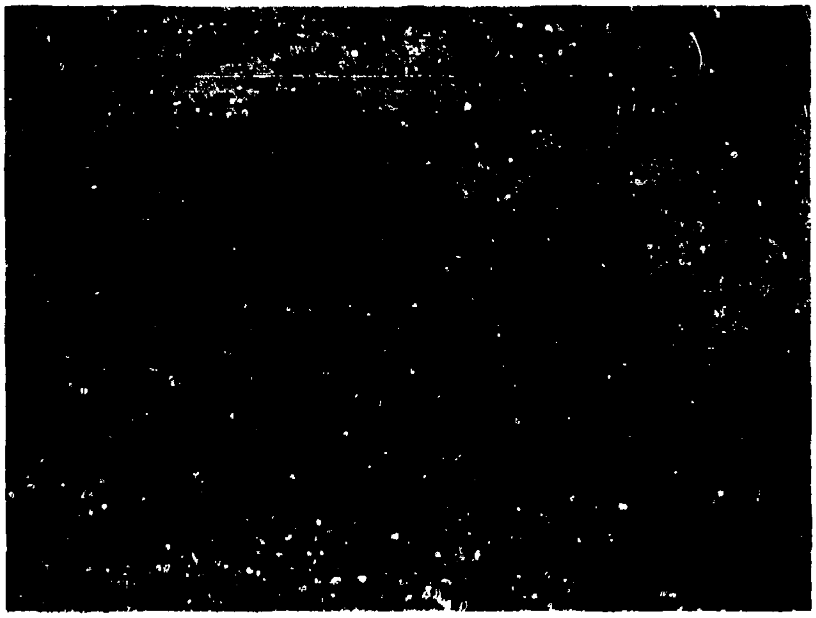


Figure N.4. Wire Mesh Samplers Being Prepared for Transport to the Laboratory After Source/Dissemination Trial, Carbon Fiber Pool Fire Test.

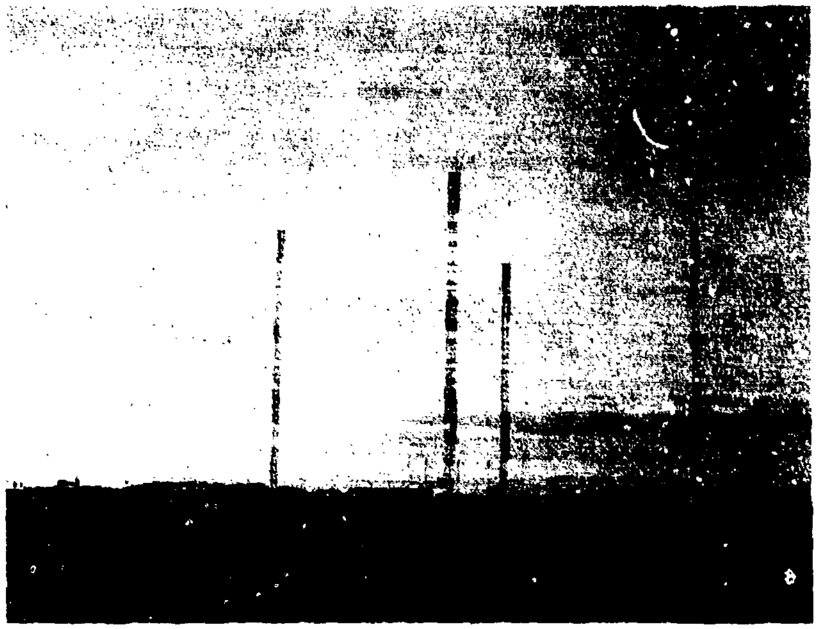


Figure N.5. "Peterson" Samplers in Position Prior to Carbon Fiber Pool Fire Test.

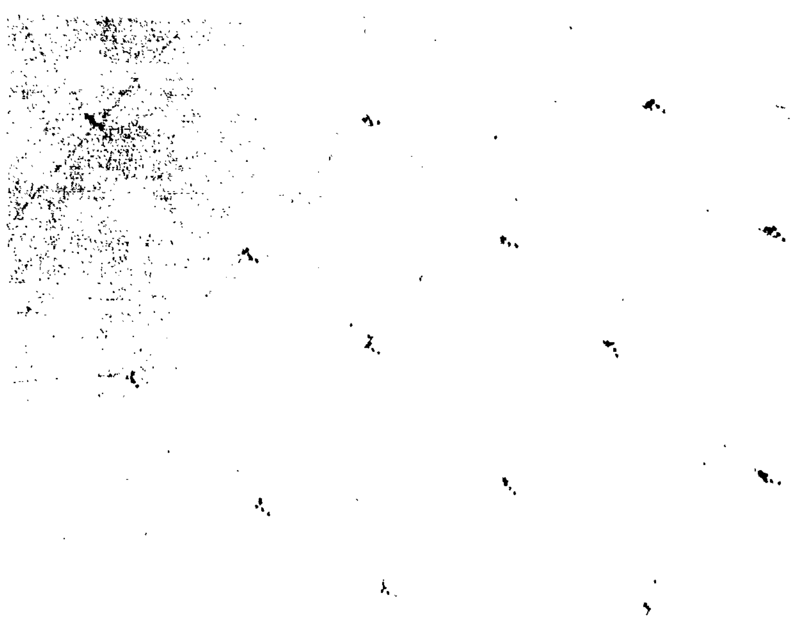


Figure N.6. "Peterson" Samplers in Position Prior to Carbon Fiber Pool Fire Test.

Figure N.7. Ignition System (SS-11 Pyrotechnic Tracer) for Carbon Fiber Pool Fire Test.

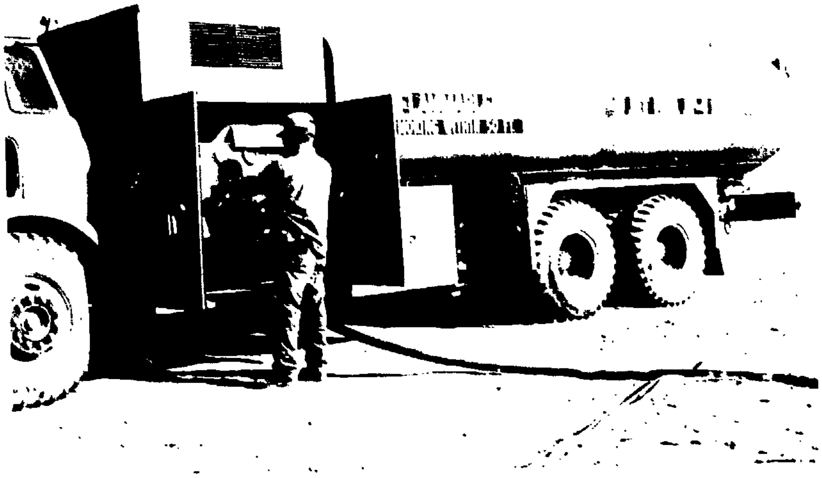


Figure N.8. Check-out Prior to Pumping JP-4 into Pit, Carbon Fiber Pool Fire Test.

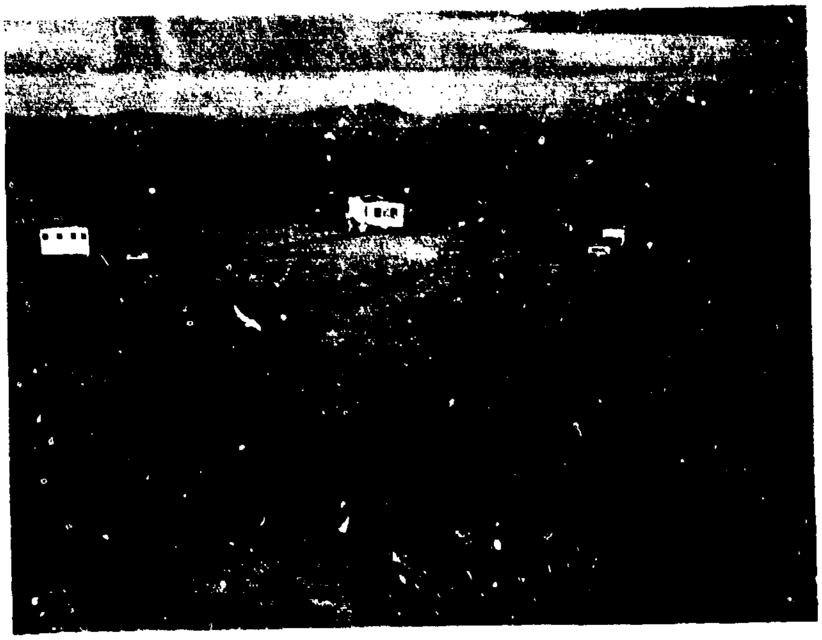


Figure N.9. Command Post Area and Support Personnel for Carbon Fiber Pool Fire Test.

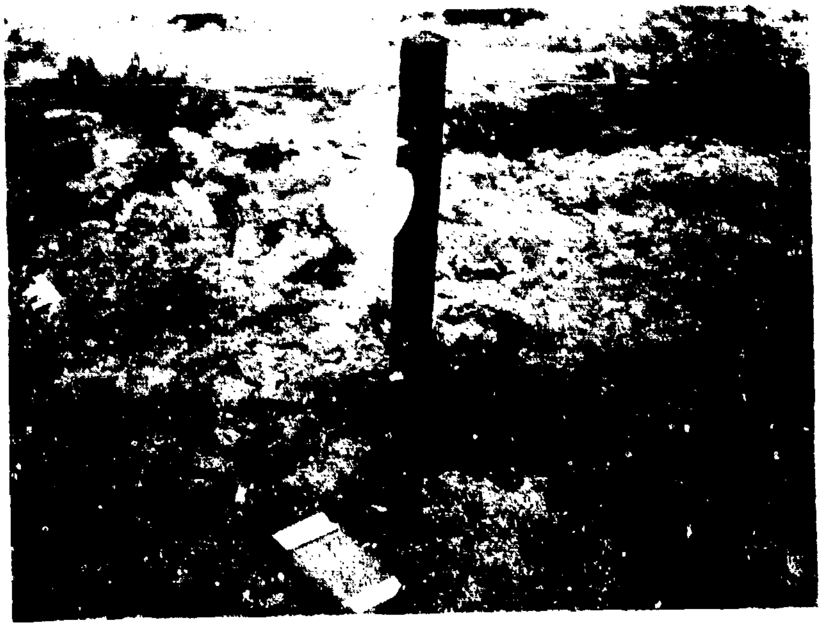


Figure N.10. Nylon Mesh Sampler and Sticky Paper Sampler for Carbon Fiber Pool Fire Test.

Figure N.11. Removing Thermocouple from "Peterson" Sampler after Source Trial, Carbon Fiber Pool Fire Test

Figure N.12. Collecting Mesh Samplers after Source Trial, Carbon Fiber Pool Fire Test.

Figure N.13. "Peterson" Samplers Ready for Transport to Laboratory After Source Trial, Carbon Fiber Pool Fire Test.

Figure N.14. "Peterson" Sampler and Wire Mesh Sampler After Source Trial, Carbon Fiber Pool Fire Test.

APPENDIX O. PICTORIAL RECORD OF CARBON FIBER FIRE (BURN) TESTS, BY TRIAL.

Figure O.1. Composite Material Positioned on Stand Prior to Trial D-1, Carbon Fiber Pool Fire Test (viewed from Northeast Tower).

Figure O.2. F-15 Speed Brake (Partial) on Stand Prior to Trial D-1, Carbon Fiber Pool Fire Test (viewed from Northeast Tower).

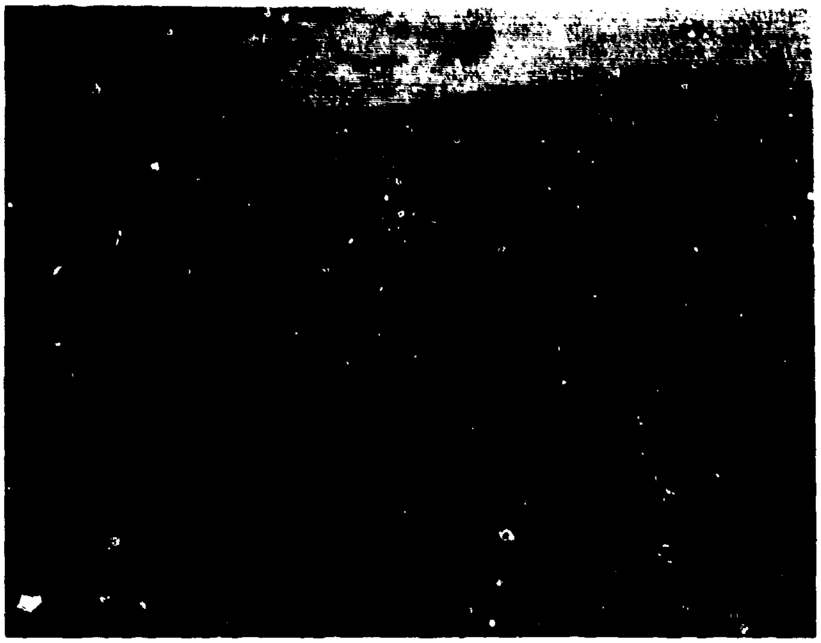


Figure O.3. Instrumentation Personnel Installing Thermocouples Prior to Trial D-1, Carbon Fiber Pool Fire Test.

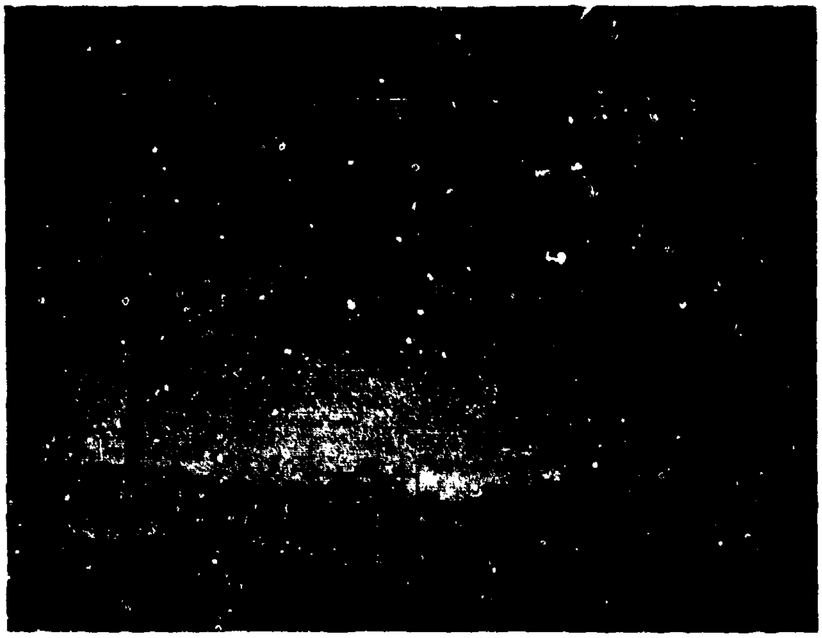


Figure O.4. JP-4 Ignition on Trial D-1, Carbon Fiber Pool Fire Test.

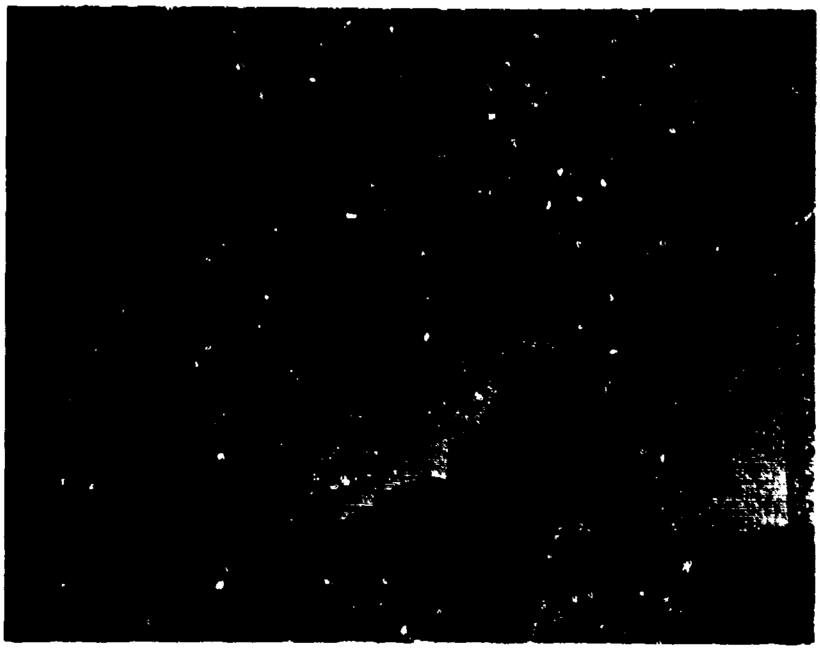


Figure 0.5. Trial D-1 After JP-4 Ignition, Carbon Fiber Pool Fire Test.

Figure 0.6. Trial D-1 After Seven Minutes of Burn, Carbon Fiber Pool Fire Test.

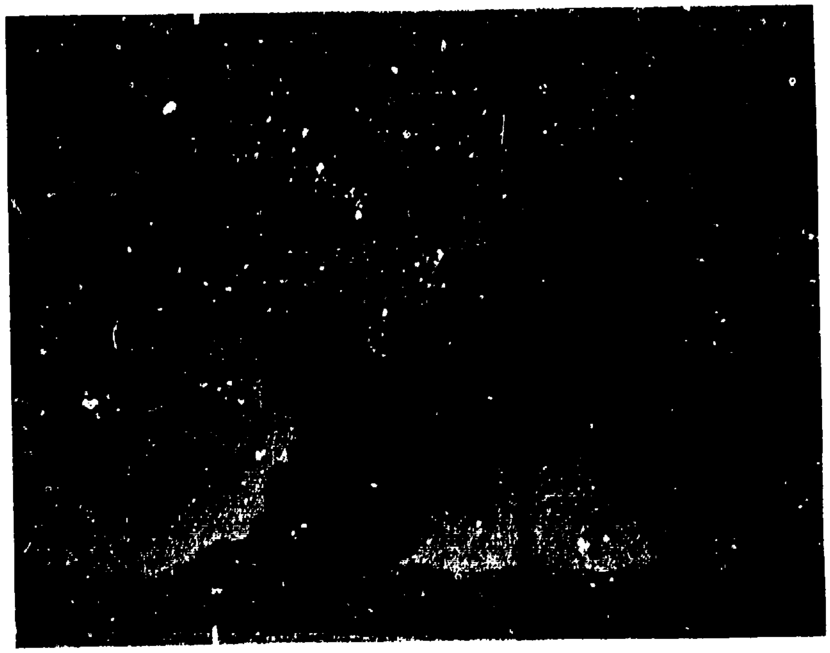


Figure 0.7. Trial D-1 After Fifteen Minutes of Burn, Carbon Fiber Pool Fire Burn Test.

Figure 0.8. Trial D-1 Residue Flame After Initial Flame (not incuded in total burn time), Carbon Fiber Pool Fire Test.

Figure 0.9. Trial D-1 Residue Flame Out, Carbon Fiber Pool Fire Test.

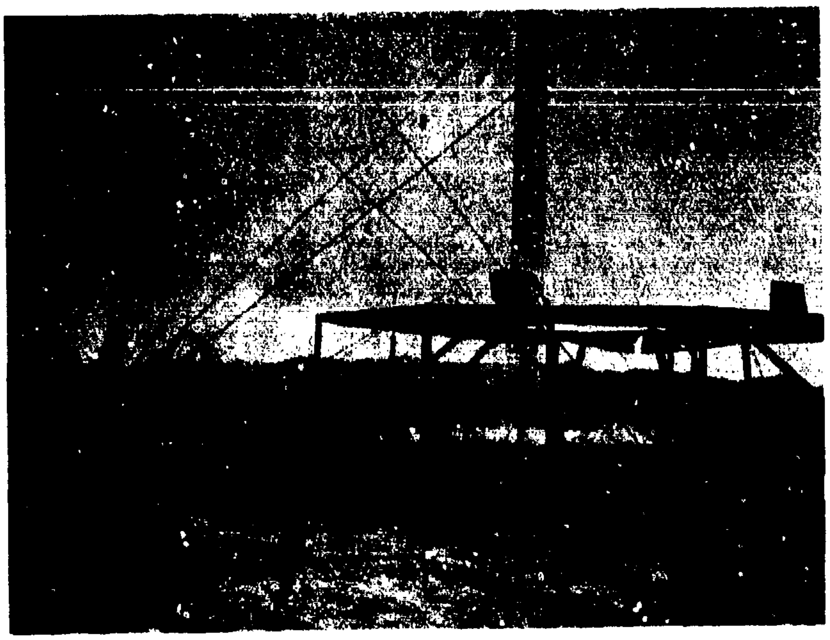


Figure 0.10. Spraying Water Mist Onto Carbon Fiber Composite Residue After Trial D-1, Carbon Fiber Pool Fire Test.

Figure O.11. Carbon Fiber Residue After Trial D-1, Carbon Fiber Pool Fire Test (viewed from Northeast Tower).

Figure O.12. Carbon Fiber Residue After Trial D-1, Carbon Fiber Pool Fire Test (viewed from Northwest Tower).

Figure 0.13. Composite Material Positioned on Stand Prior to Trial D-2, Carbon Fiber Pool Fire Test (viewed from Northeast Tower).

Figure 0.14. Pumping JP-4 Fuel into Fire Pool, with fire fighting Crew at standby, Prior to Trial D-2, Carbon Fiber Pool Fire Test.

Figure 0.15. JP-4 Ignition During Trial D-2, Carbon Fiber Pool Fire Test.

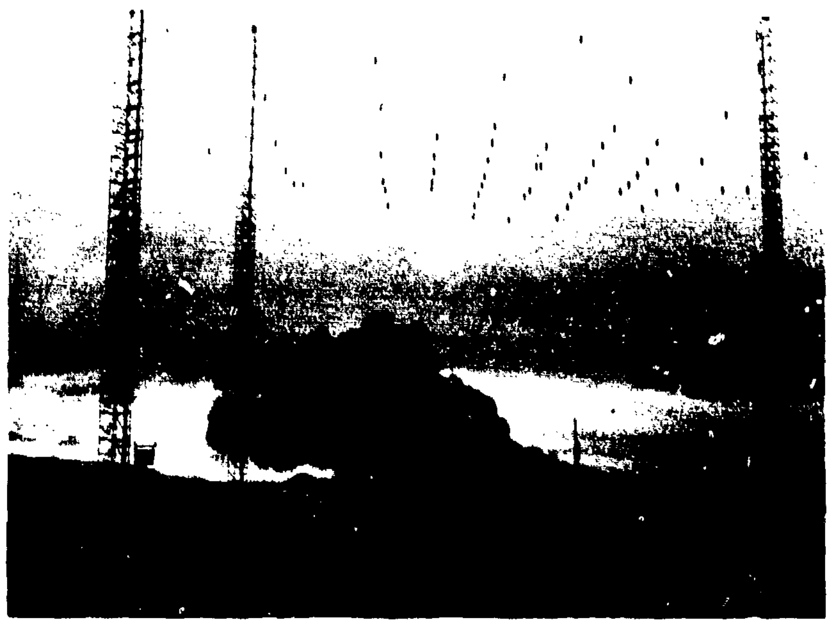


Figure 0.16. Trial D-2 After JP-4 Ignition, Carbon Fiber Pool Fire Test.

Figure 0.17. Looking East During Trial D-2, Carbon Fiber Pool Fire Test.

Figure 0.18. Looking West During Trial D-2, Carbon Fiber Pool Fire Test.

Figure 0.19. Looking Southeast During Trial D-2, Carbon Fiber Pool Fire Test.

Figure 0.20. Trial D-2 at End of Burn, Carbon Fiber Pool Fire Tests.

Figure O.21. Trial D-2 Thirty-five Minutes After Ignition, Carbon Fiber Pool Fire Test.

Figure O.22. Carbon Fiber Composite Residue from Trial D-2, Carbon Fiber Pool Fire Test.

Figure 0.23. Carbon Fiber Composite Residue from Trial D-2, Carbon Fiber Pool Fire Test.

Figure 0.24. F-16 Aircraft Carbon Fiber Composite Material Prior to Trial D-3, Carbon Fiber Fire Pool Trial.

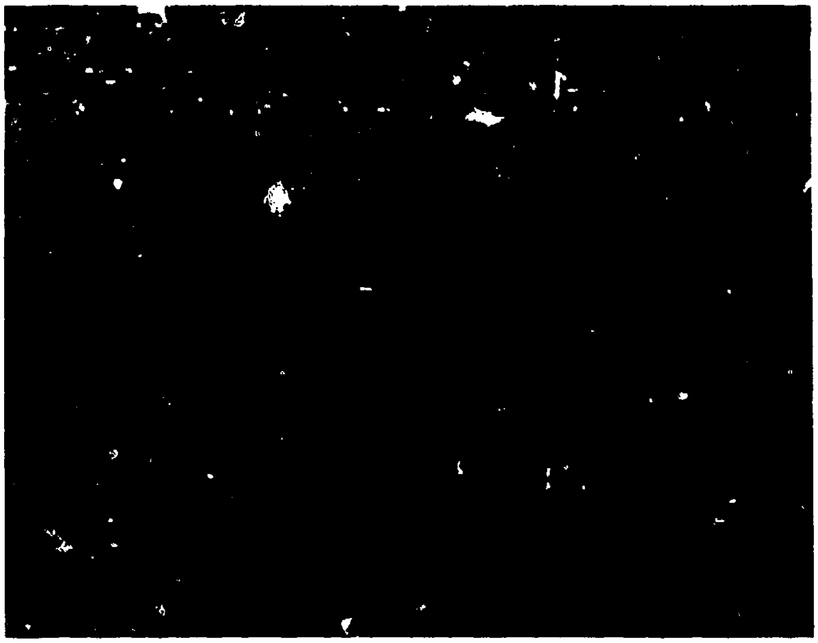


Figure 0.25. Carbon Fiber Composite Material and Thermocouple Installation Prior to Trial D-3, Carbon Fiber Pool Fire Test.

Figure 0.26. Looking South During Trial D-3, Carbon Fiber Pool Fire Test.

Figure 0.27. Close in View of Dense Soot Plume, Looking South During Trial D-3, Carbon Fiber Pool Fire Test.

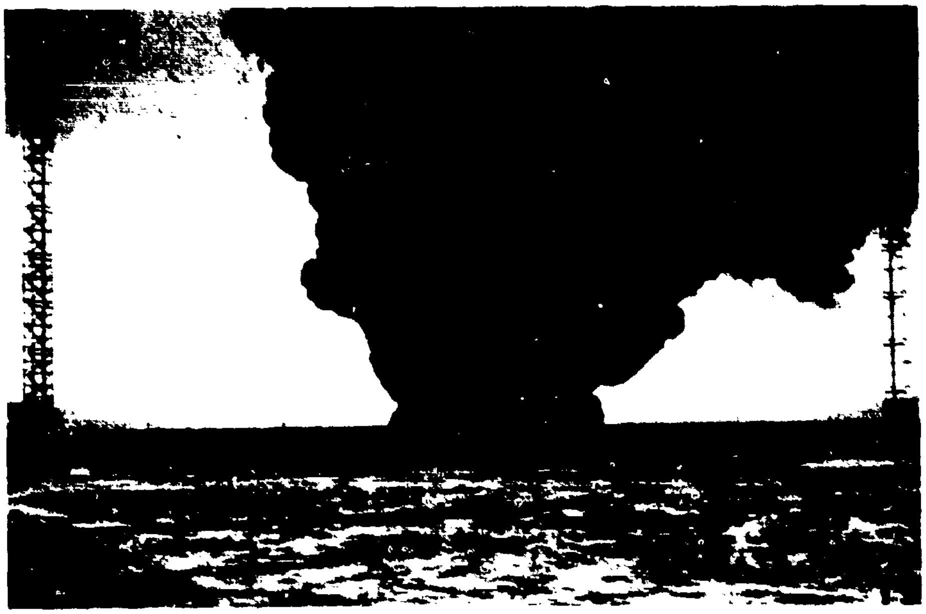


Figure 0.28. Looking Southeast During Trial D-3, Carbon Fiber Pool Fire Test.

Figure 0.29. Looking East During Trial D-3, Carbon Fiber Pool Fire Test.

Figure 0.30. Looking Southeast From Helicopter During Trial D-3, Carbon Fiber Pool Fire Test.

Figure 0.31. Looking West from Helicopter During Trial D-3, Carbon Fiber Pool Fire Test.

Figure 0.32. Looking South from Helicopter During Trial D-3, Carbon Fiber Pool Fire Tests.

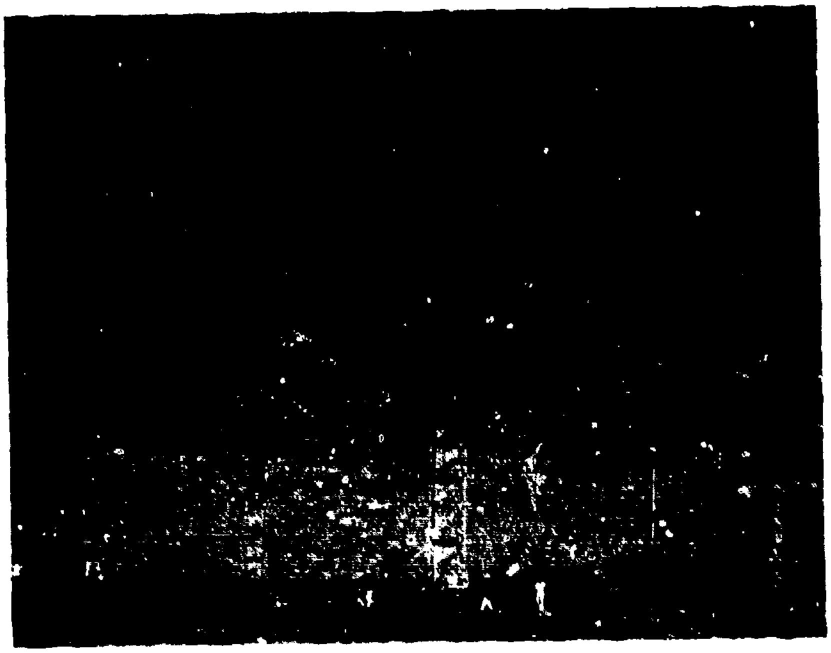


Figure 0.33. Visual Evaluation After Trial D-3, Carbon Fiber Pool Fire Test.

Figure 0.34. Burned F-16 Vertical Stabilizer, Trial D-3, Carbon Fiber Pool Fire Tests.

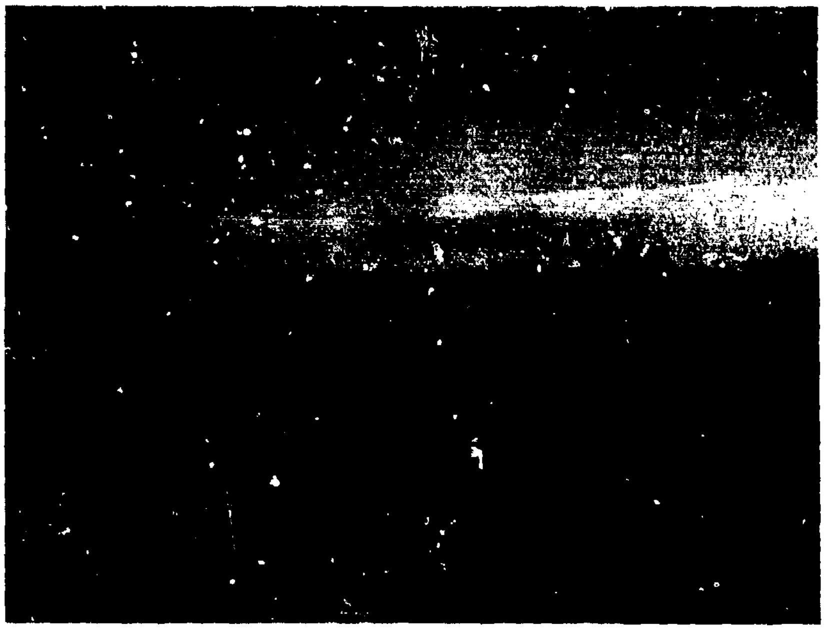


Figure 0.35. Collapsed Metal Sample Support Stand After Trial D-3, Carbon Fiber Pool Fire Test.

Figure 0.36. Carbon Fiber Residue for Trial D-3, Carbon Fiber Pool Fire Test.

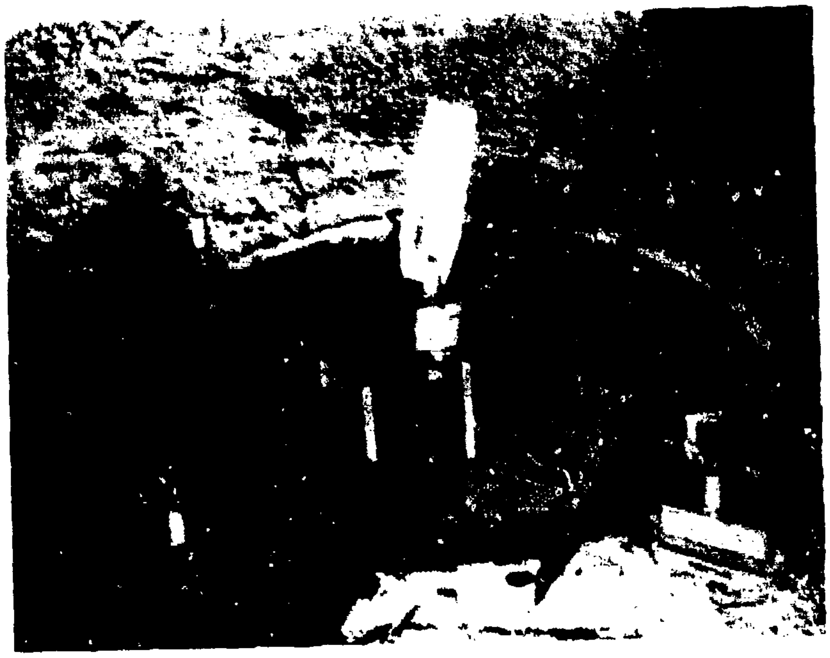


Figure 0.37. View of South Burn Pit Prior to Trial S-1, Carbon Fiber Pool Fire Test.

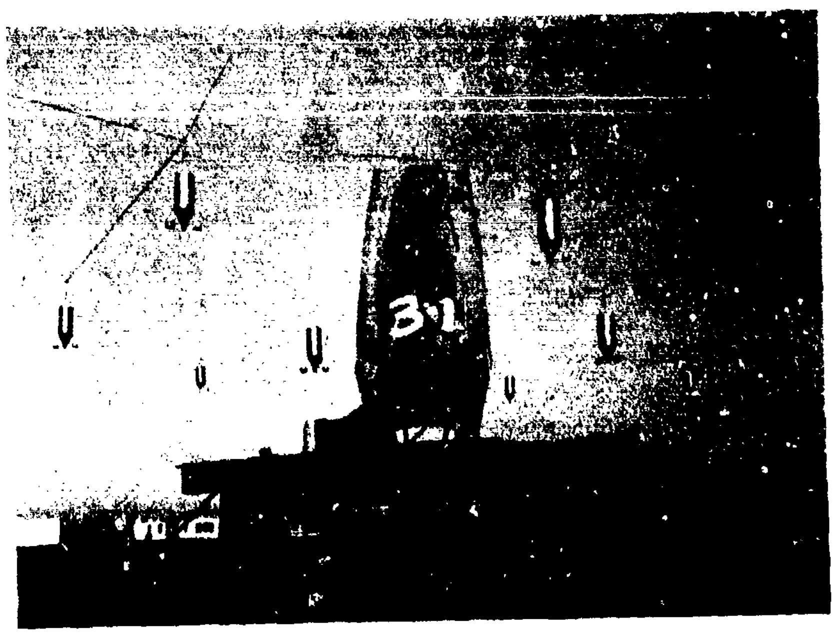


Figure 0.38. Composite Material Prior to Trial S-1, Carbon Fiber Pool Fire Test.

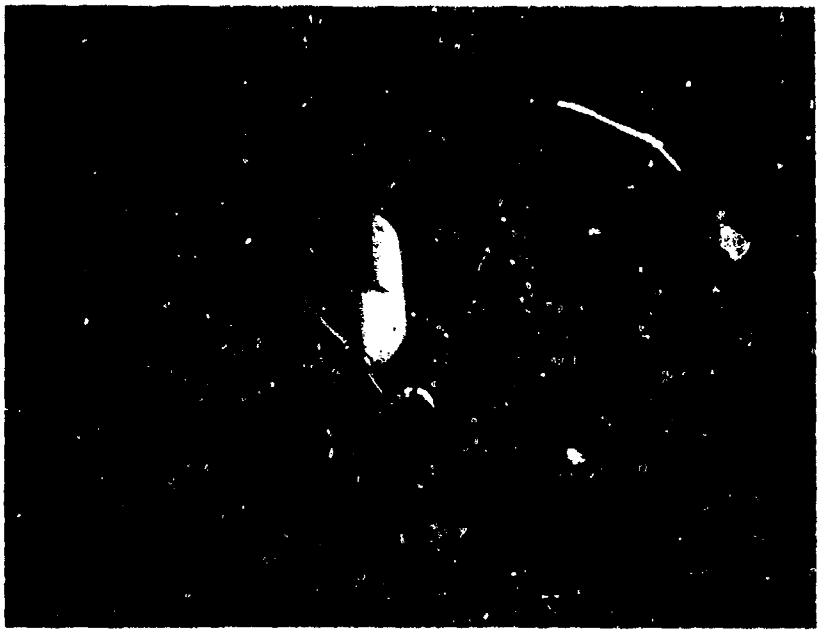


Figure 0.39. Setup of "Peterson" and Wire Mesh Samplers on Trial S-1, Carbon Fiber Pool Fire Test.

Figure 0.40. JP-4 Ignition on Trial S-1, Carbon Fiber Pool Fire Test.

Figure 0.41. Trial S-1 After JP-4 Ignition, Carbon Fiber Pool Fire Test.

Figure 0.42. Looking Northeast from Helicopter During Trial S-1 Carbon Fiber Pool Fire Test.

Figure 0.43. Looking North from Helicopter During Trial S-1, Carbon Fiber Pool Fire Test

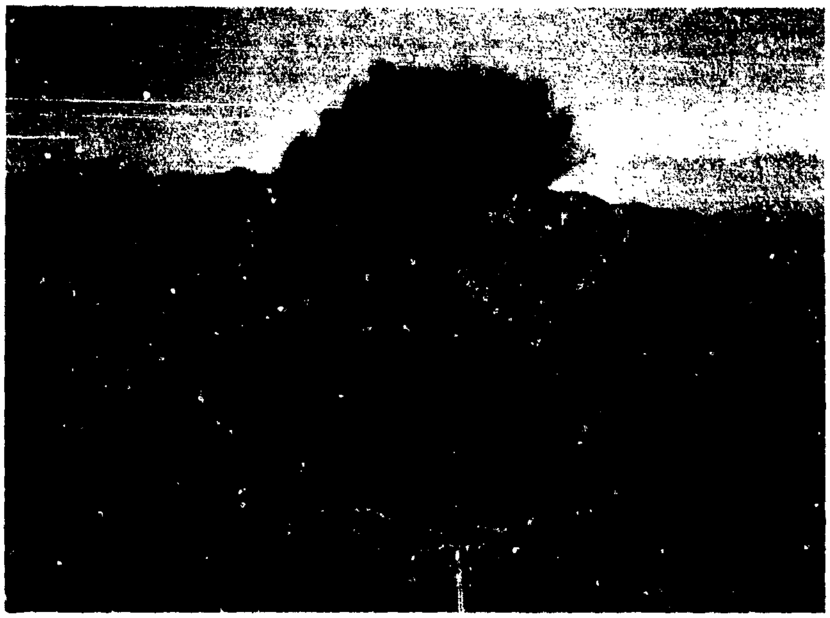


Figure 0.44. Looking West from Helicopter During Trial S-1, Carbon Fiber Pool Fire Test.

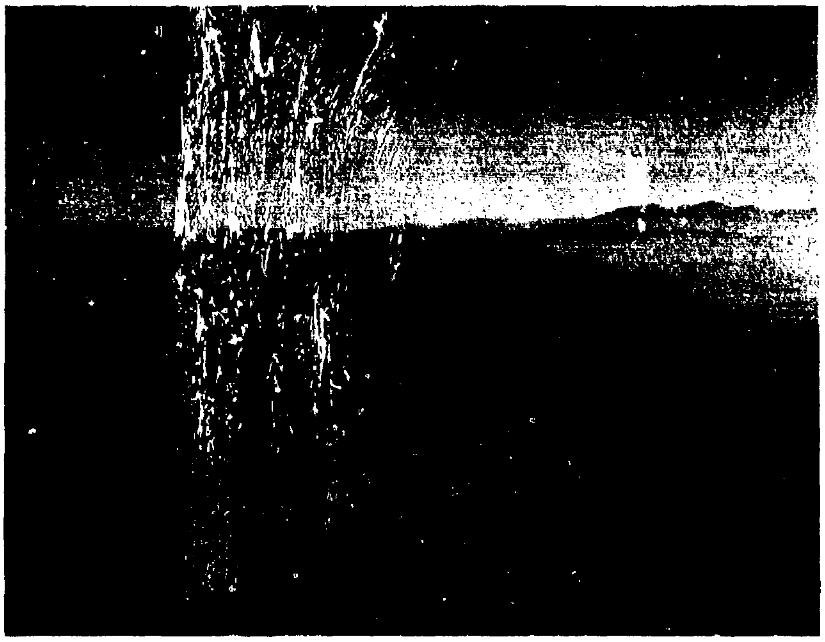


Figure 0.45. Looking Northeast from Helicopter During Trial S-1, Carbon Pool Fire Test.

Figure 0.46. Looking West from Helicopter During Trial S-1, Carbon Fiber Pool Fire Tests.

Figure 0.47. Looking Southwest from Helicopter During Trial S-1, Carbon Fiber Pool Fire Test.

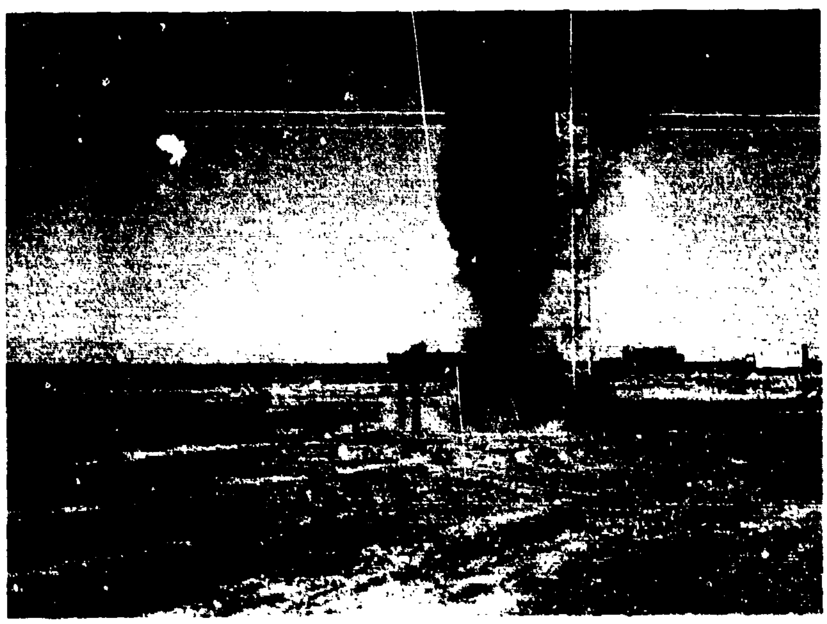


Figure 0.48. End of Burn on Trial S-1, Carbon Fiber Pool Fire Test.

Figure 0.49. Carbon Fiber Burn Area After Trial S-1, Carbon Fiber Pool Fire Test.

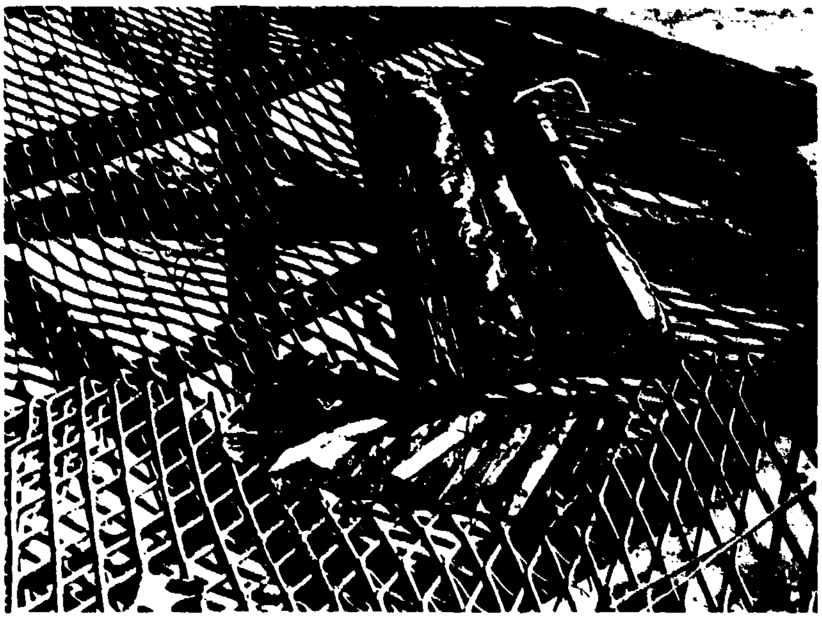


Figure 0.50. Composite Residue After Trial S-1, Carbon Fiber.

Figure 0.51 Composite Residue After Trial S-1, Carbon Fiber Pool Fire Test.

Figure 0.52. Composite Residue After Trial S-1, Carbon Fiber Pool Fire Test.

Figure 0.53. Composite Material Prior to Trial S-2, Carbon Fiber Pool Fire Test.

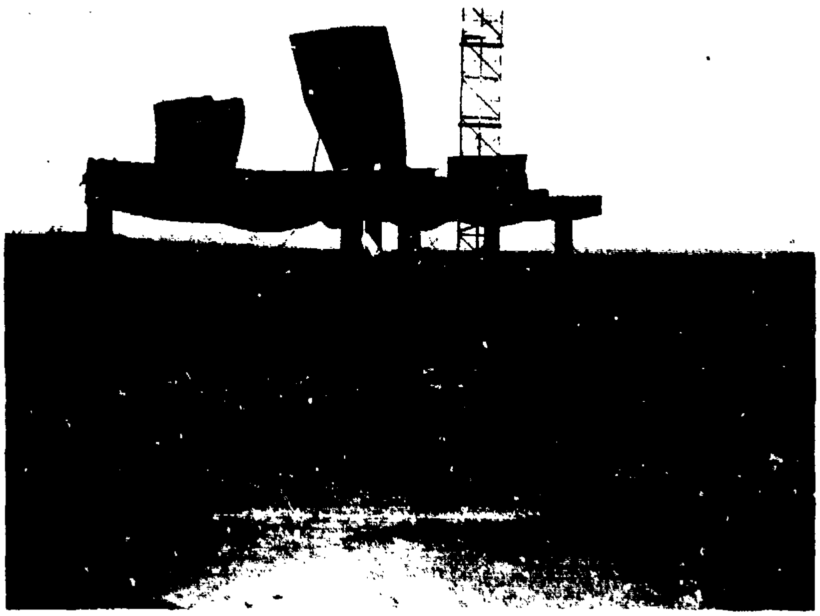


Figure 0.54. Composite Material and Ignition System Setup Prior to Trial S-2, Carbon Fiber Pool Fire Test.

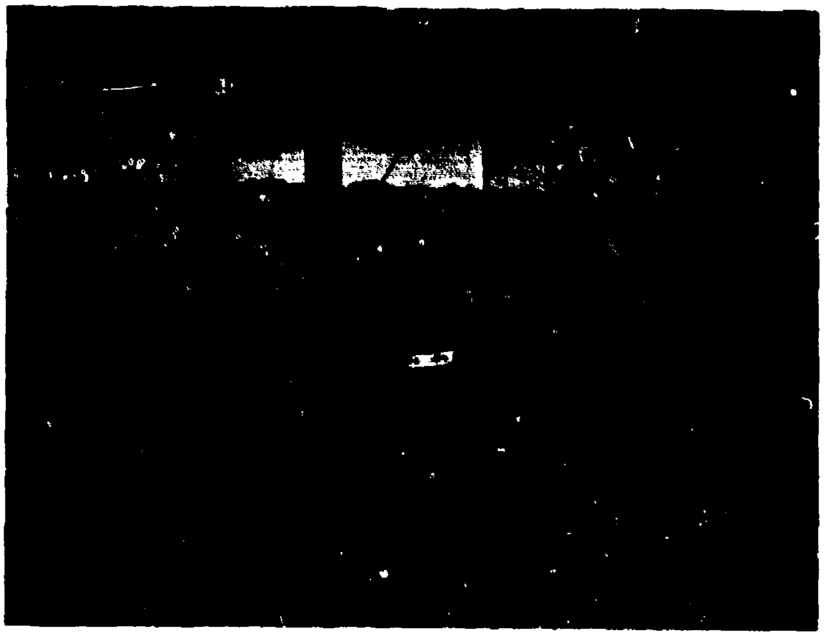


Figure 0.55. Composite Plates on 0.5-M Stand Prior to Trial S-2, Carbon Fiber Pool Fire Test.

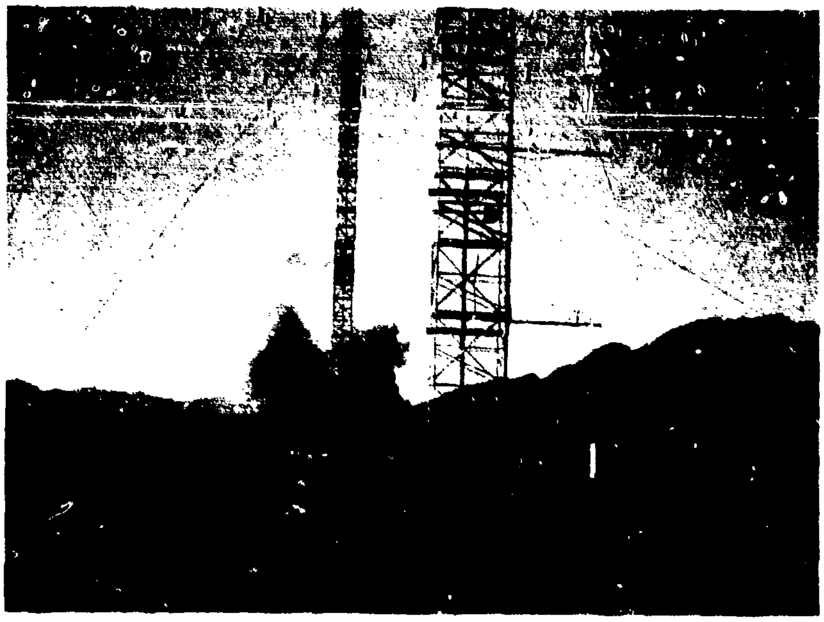


Figure 0.56. JP-4 Ignition on Trial S-2, Carbon Fiber Pool Fire Test.

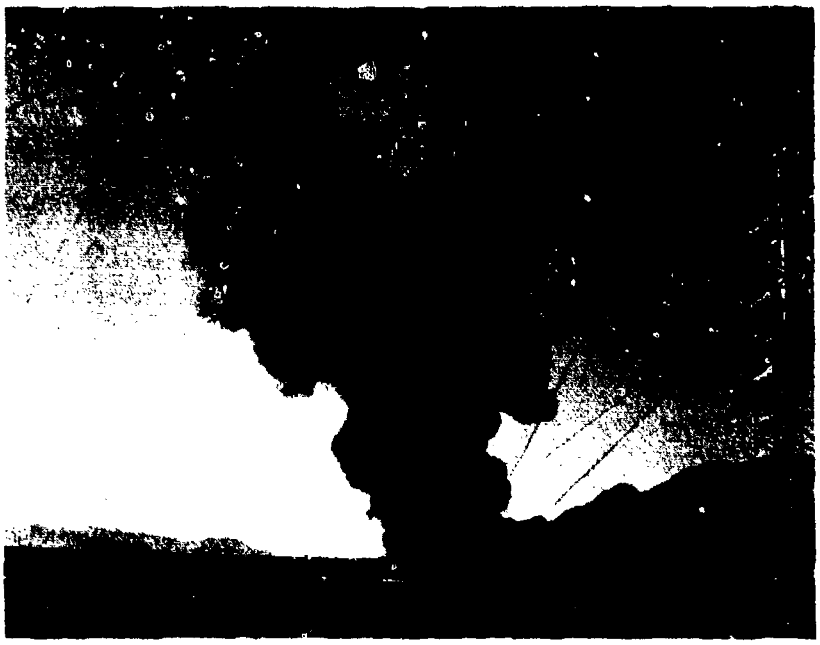


Figure 0.57. Tiral S-2 After JP4 Ignition, Carbon Fiber Pool Fire Test.

Figure 0.58. Trial S-2 During Burn, Carbon Fiber Pool Fire Test.

Figure 0.59. Trial S-2, Smoke Cloud Drifting to the South, Carbon Fiber Pool Fire Test.

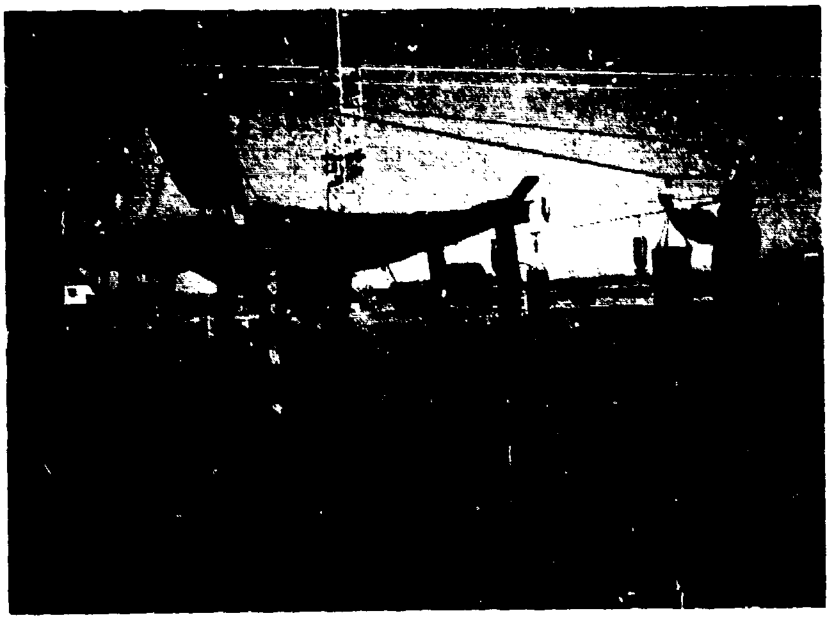


Figure 0.60. Sampler Pickup and Composite Residue After Trial S-2, Carbon Fiber Pool Fire Test.

Figure O.61. Residue From Composite Plates After Trial S-2, Carbon Fiber Pool Fire Test.

APPENDIX P. PICTORIAL DISPLAY OF AFGL BALLOON OPERATIONS AND NASA/TRW JACOB'S LADDER

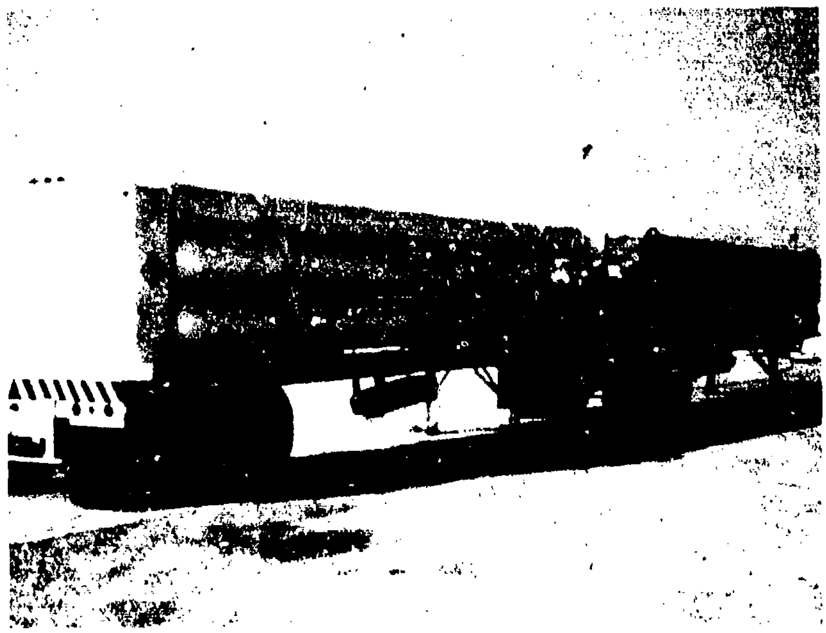


Figure P.1. Helium Trailers for Support of Jacob's Ladder Balloon Launch, Carbon Fiber Pool Fire Test.

Figure P.2. Personnel Unfolding Balloon, Carbon Fiber Pool Fire Test.

Figure P.3. Personnel Unfolding Balloon, Carbon Fiber Pool Fire Test.

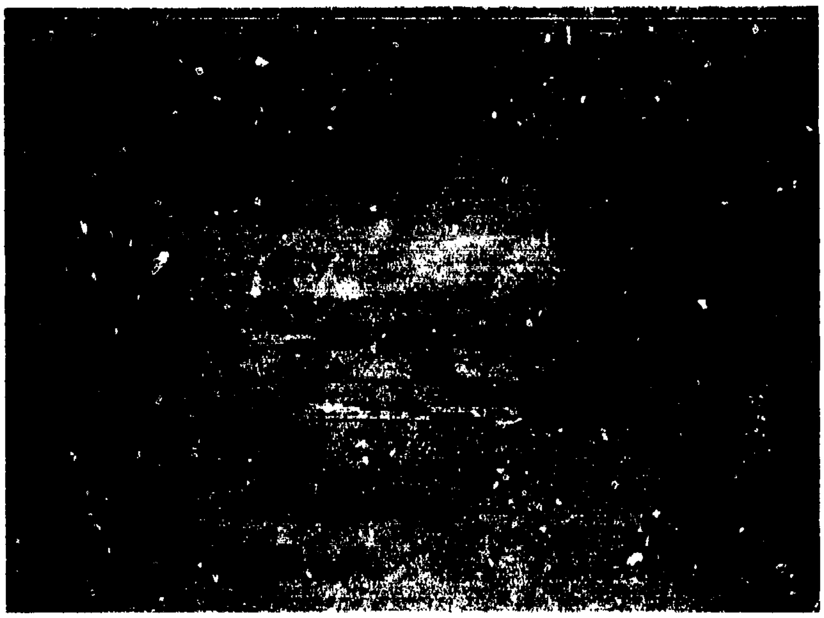


Figure P.4. Personnel Starting Balloon Inflation, Carbon Fiber Pool Fire Test.

Figure P.5. Balloon Inflation in Progress, Carbon Fiber Pool Fire Test.

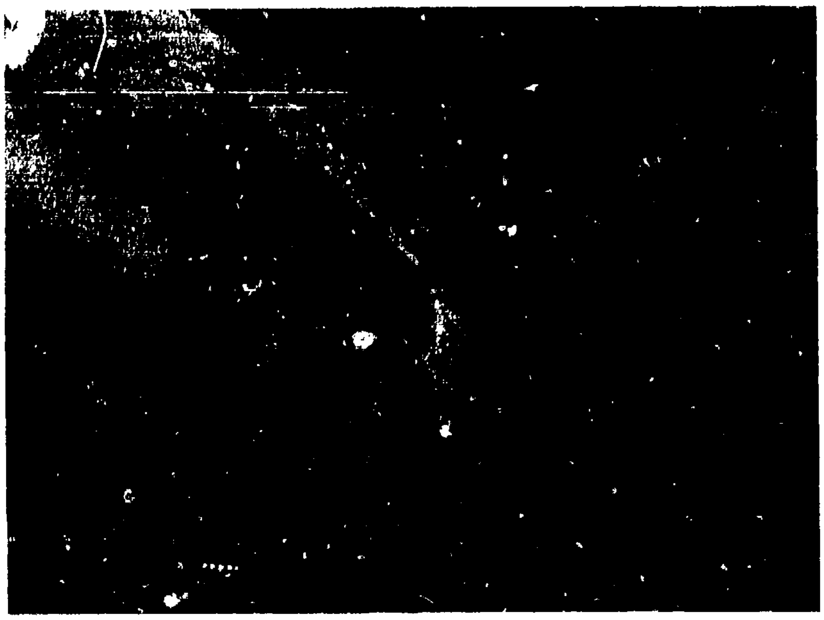


Figure P.6. Balloon Inflation in Progress, Carbon Fiber Pool Fire Test.

Figure P.7. Balloon Inflation in Progress, Carbon Fiber Pool Fire Test.

Figure P.8. Balloon Inflation in Progress, Carbon Fiber Pool Fire Test.

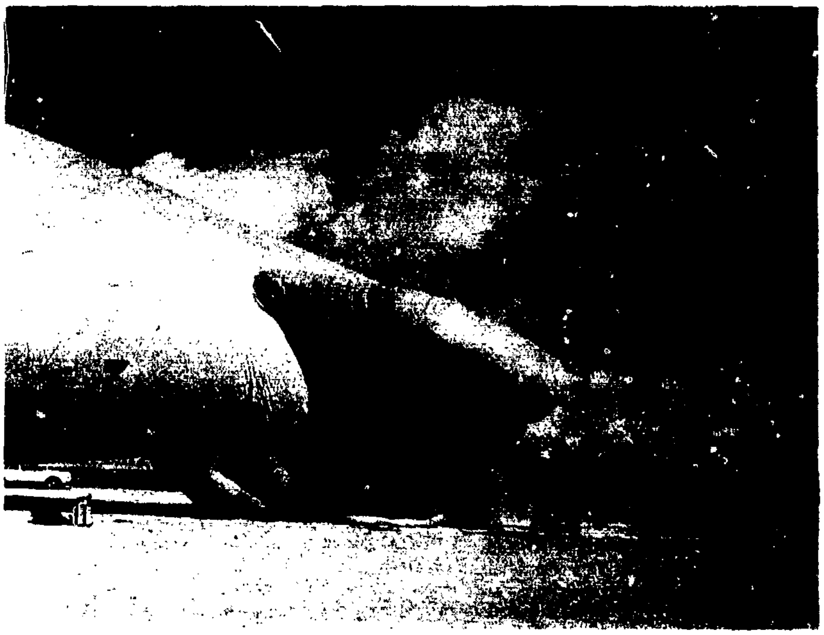


Figure P.9. Balloon Inflation in Progress, Carbon Fiber Pool Fire Test.

Figure P.10. Balloon Launch in Progress, Carbon Fiber Pool Fire Test.

Figure P.11. Balloon on Standby at 45.7 m (150 ft) Air Force Geophysics Laboratory, Carbon Fiber Pool Fire Test.

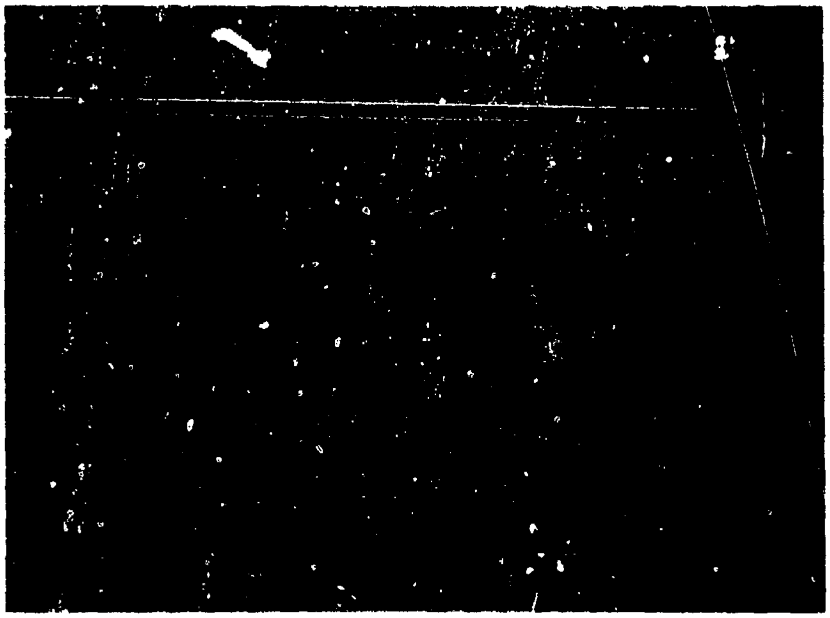


Figure P.12. Ballon at 488 m (1600 ft) Air Force Geophysics Laboratory, Suspending Jacob's Ladder, Carbon Fiber Pool Fire Test.

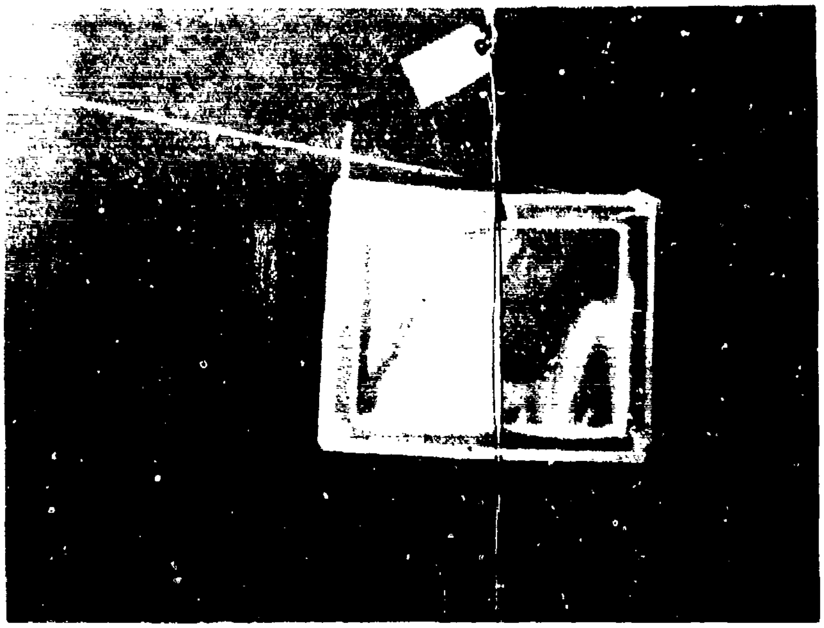


Figure P.13. View-graph Mesh Sampler (TRW) Attached to Jacob's Ladder, Carbon Fiber Pool Fire Test.

Figure P.14. Crews Retrieving Balloons for Deflation, Carbon Fiber Pool Fire Test.

Figure P.15. Balloon Deflation in Progress, Carbon Fiber Pool Fire Test.

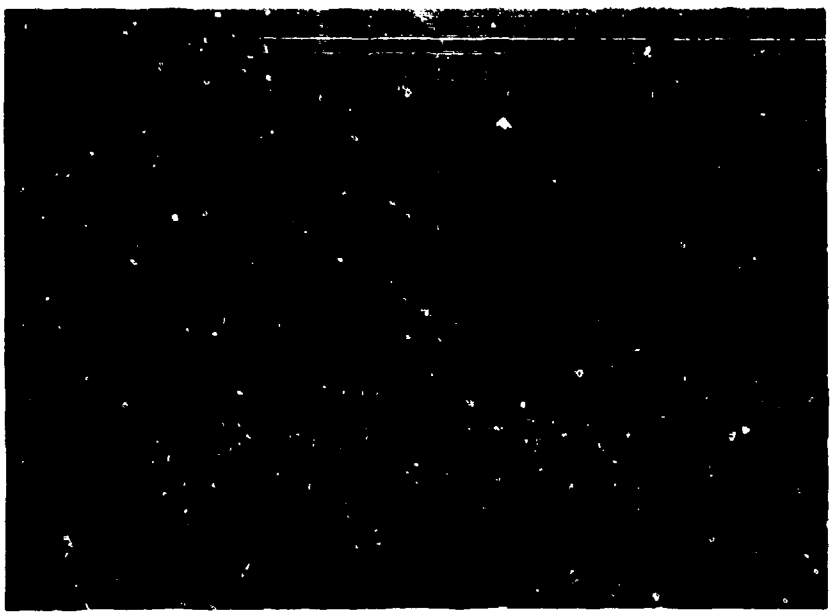


Figure P.16. Balloon Deflation in Progress, Carbon Fiber Pool Fire Test.

Figure P.17. Balloon Deflation in Progress, Carbon Fiber Pool Fires Test.

Figure P.18. Balloon Inflation in Progress During Darkness, Carbon Fiber Pool Fire Test.

Figure P.19. Balloon Inflation in Progress During Darkness, Carbon Fiber Pool Fire Test.

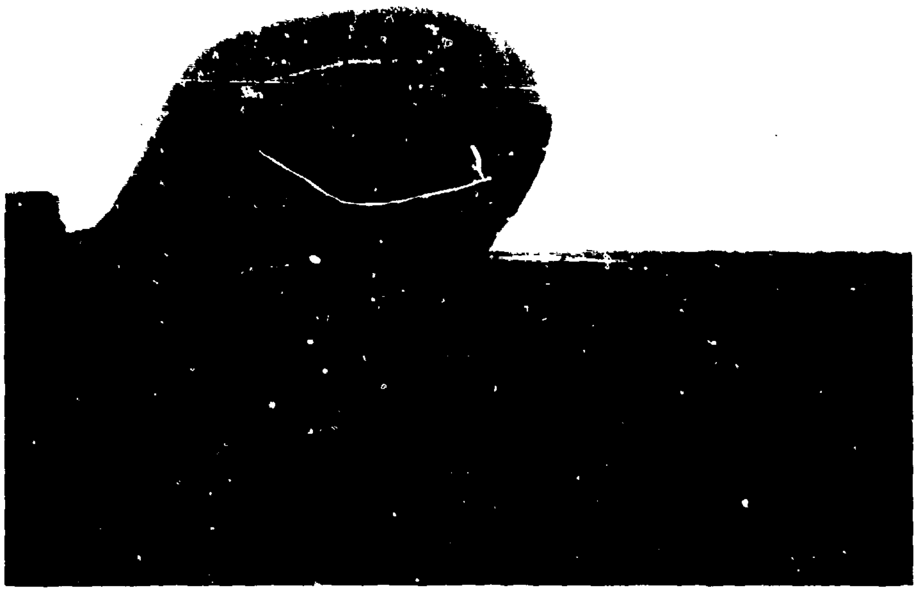


Figure P.20. Balloon Inflation in Progress at Sunrise, Carbon Fiber Pool Fire Test.

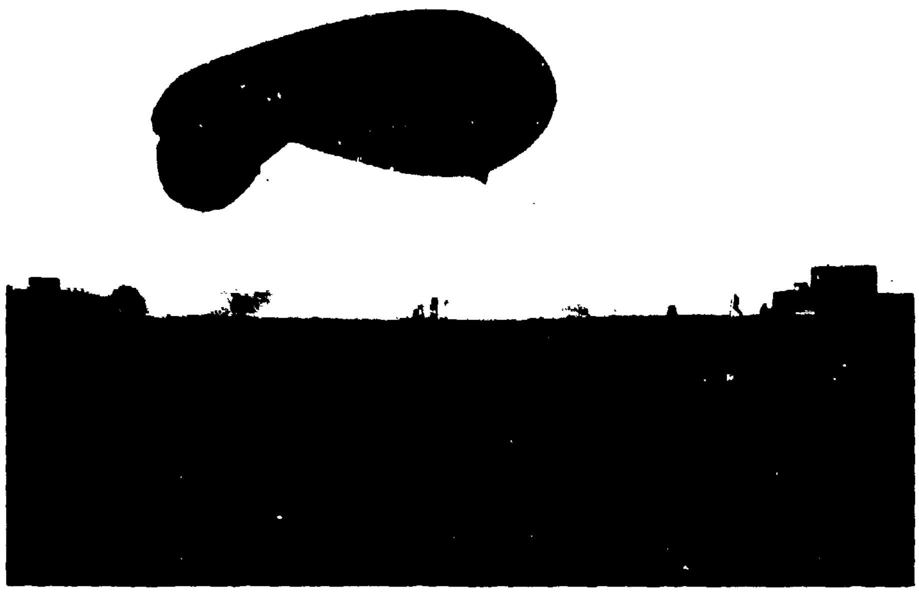


Figure P.21. Balloon Launch at Sunrise, Carbon Fiber Pool Fire Test.

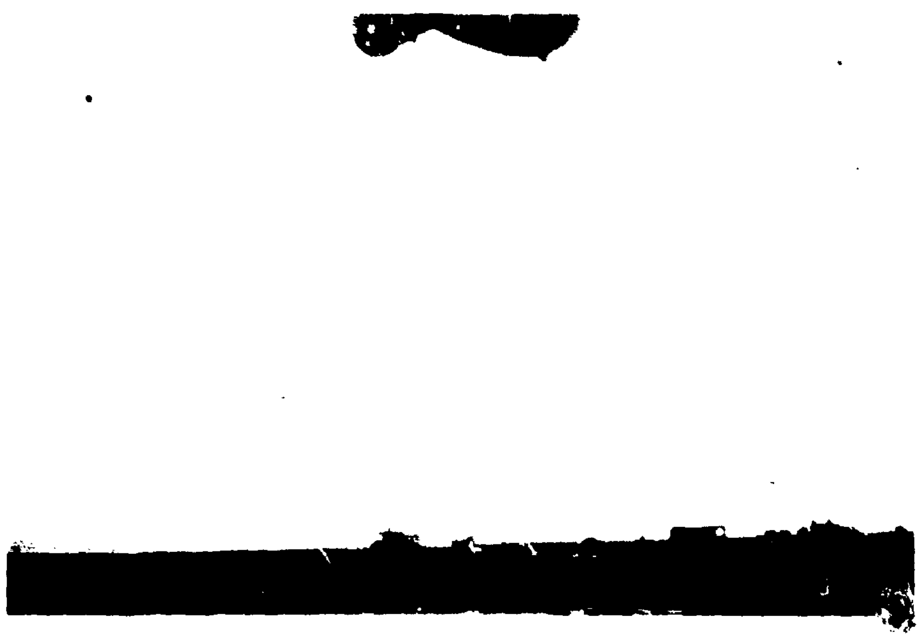


Figure P.22. Balloon on Standby at 45.7 m (150 ft) at Sunrise, Air Force Geophysics Laboratory, Carbon Fiber Pool Fire Test.

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